A GUIDE TO IMPLEMENTING RECLAMATION PROCESSES AT DEPARTMENT OF DEFENSE MUNICIPAL SOLID WASTE AND CONSTRUCTION DEBRIS LANDFILLS

THESIS

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
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Gregory L. Tures, B. Arch.
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To my friends and family.

Gregory L. Tures

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Abstract

This thesis serves as a guide for implementing landfill reclamation techniques on municipal solid waste or construction debris landfills owned, operated, or used by the DoD. The research describes historical and current methods for disposing of solid waste including open dumping, sanitary landfilling, and the development of "state-of-the-art" sanitary landfill cell technology. The thesis also identifies the factors which have led to the need for new methods of managing municipal solid waste. The vast majority of the study is devoted to identifying actions which should be taken before, during, and after implementation of a landfill reclamation project. These actions include the development of health, safety, and contingency planning documents, the establishment of systems for characterizing and monitoring site conditions, and the identification of other procedures and processes necessary for performing successful operations. Finally, this study contains a model for analyzing under which conditions reclamation is economically feasible. The model examines economic feasibility in four separate conditions and shows that reclamation is economically feasible in a wide variety of markets. However, the model also shows that feasibility is directly associated with a continuance of normal landfilling operations while reclamation is in progress.

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I. Introduction

Background

Since the end of the 1960's the trend in landfilling is that the available space for burying municipal solid waste (MSW) is being depleted rapidly (Sayers, 1991: 448). The expense and complexities of operating existing landfills, combined with the difficulties of siting and constructing new facilities, are also of concern and are important problems that must be addressed. Additionally, methods which have the potential to reduce liability and allow MSW to be managed safely and economically are highly desirable.

Solutions that respond to these problems are also necessary due to recent assessments which indicate that MSW landfills have significant potential to directly affect human health. This point is illustrated in a 1991 report published by the United States Environmental Protection Agency (EPA) which states:

> Approximately 20 percent of the sites on the National Priorities List are landfills where a combination of principally municipal and to a lesser extent hazardous waste, has been co-disposed. (EPA, 1991:1-1)

One technique of MSW management that responds to these problems is the process of landfill reclamation or landfill mining. This process entails excavating existing landfill cells in order for the once-buried waste to be reprocessed, reconsolidated, and otherwise managed or re-used such that the footprint of the landfill is reduced (Lee, 1991: 32).

Both MSW and construction debris landfills contain material with high potential for re-use including large quantities of paper, metal, plastic, glass, soil/organic material, rock, rubble, and other inorganics (Figure 1-1 and Figure 1-2). After the re-usable material is removed and the non-marketable fraction is consolidated and re-buried, significant landfill volume is once again available for continued disposal operations. The potential for landfill re-use, the DoD's emphasis on pollution prevention programs, and the increasing scarcity of MSW sites makes consideration of landfill mining mandatory to current solid waste disposal practices.

Research Purpose and Objectives

The primary purpose of this research is to provide DoD installations with guidelines for implementing a facility landfill reclamation program. As part of these guidelines, this thesis will include detailed descriptions of the process, procedures, and economic considerations necessary for conducting a successful landfill reclamation project. A major objective of this thesis will be to provide a means for an installation environmental manager to determine if

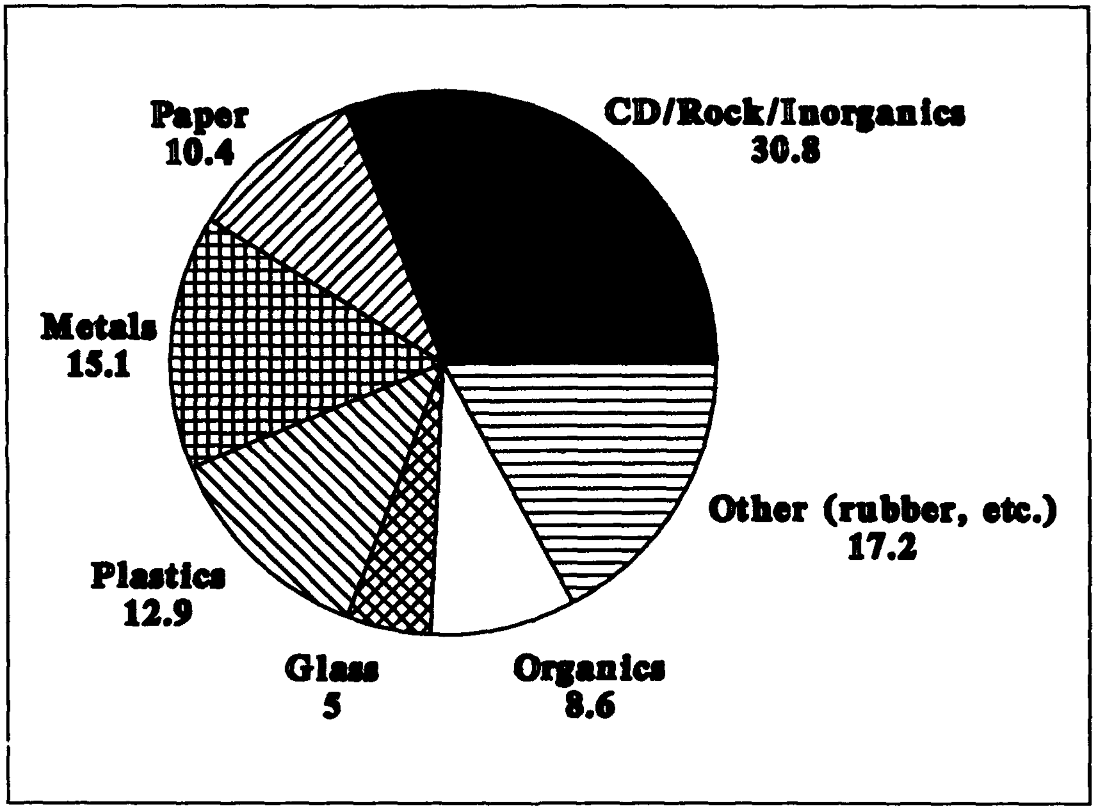


Figure 1-1. Material Mined from a MSW Landfill by Percentage of Total Volume (Murphy, 1993)

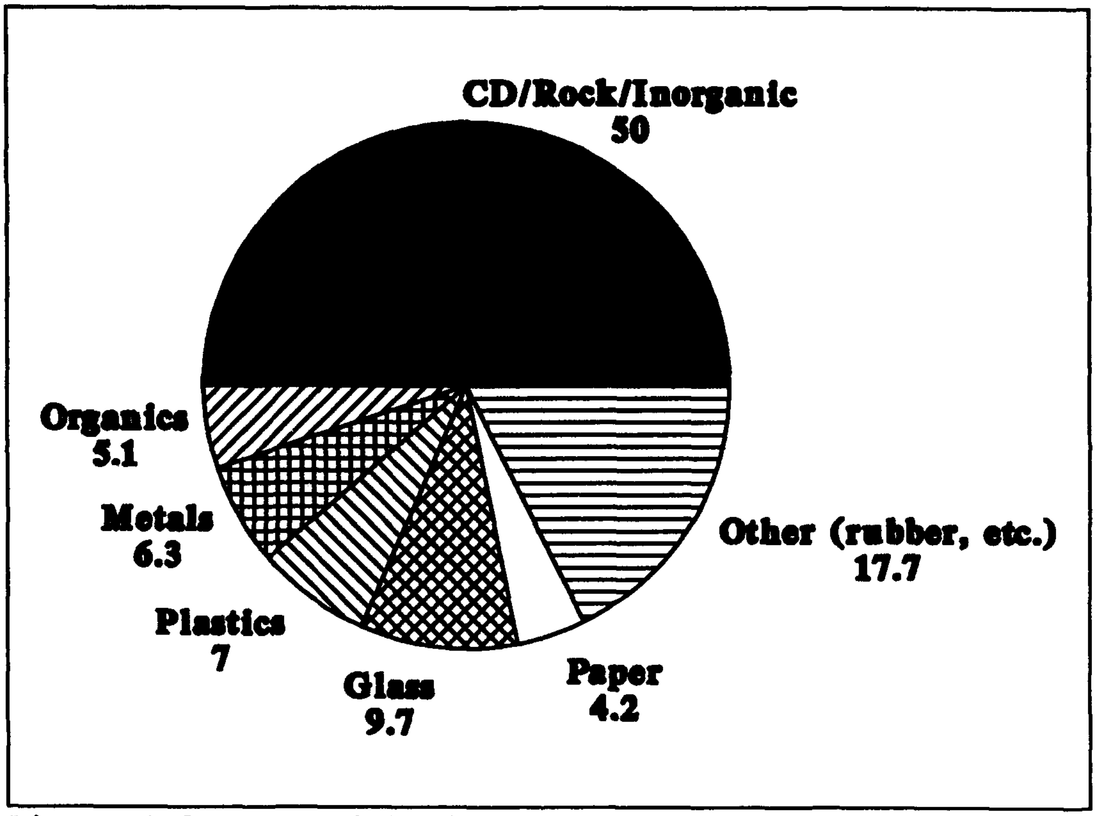


Figure 1-2. Material Mined from a MSW Landfill by Percentage of Total Weight (Murphy, 1993)

reclamation is financially viable at the local facility and to identify the aspects of the reclamation process which must e taken into account at the MSW or construction debris landfill to be mined.

Scope and Limitations

At this point it is important to realize that landfill reclamation may not be an appropriate technique for managing MSW at all locations. Many factors, such as the presence of hazardous or industrial waste, geography, geology, economics, or regulatory constraints may preclude implementation of the landfill reclamation process. Consequently, this thesis will provide a generalized approach to developing, implementing, and sustaining a mining program and will serve as a guide in the process of deciding whether or not a mining program should be implemented. Specific emphasis throughout the thesis will be placed on the fact that location-specific considerations will prevail over an installation's decision to reclaim a landfill.

Definitions of Terms

The following definitions and acronyms are those particular to the landfill mining process or are technical terms used throughout the thesis.

Aerobic. Existing or living in an oxygen environment.

Anaerobic. Existing or living in an oxygen-free environment.

Anoxic. An oxygen-free environment

Antagonistic. Reaction between one or more chemicals such that the effect to the body is less than the effect caused by any one of the chemicals present.

Asbestos. A fibrous mineral used extensively in a wide variety of industries. Ingestion or inhalation of asbestos is suspected of causing adverse health effects.

Asphyxiant. A medium capable of causing oxygen-deficient conditions.

Biodegradation. Decomposition of matter by biological action.

Biochemical Oxygen Demand (BOD). The amount of oxygen required by bacteria for oxidizing a compound to carbon dioxide and water (Masters, 1991: 39).

Cap. A clay, or synthetic, device used to cover a landfill cell in order to prevent the infiltration of moisture.

Chemical Oxygen Demand (COD). The amount of oxygen required to chemically oxidize a compound to carbon dioxide and water (Masters, 1991: 108).

Cell. A partition within a landfill, an excavated or hollowed area in the ground that has been constructed to accept municipal, industrial, or hazardous waste.

Construction Debris. That portion of solid waste consisting of discarded building materials, rubble, rock, wood, concrete, etc.

Cost/Benefit Analysis (CBA). See Life Cycle Cost Analysis.

Dense Non-aqueous Phase Liquid (DNAPL). A liquid not readily miscible with water and having a density greater than 1.0.

Dermal. Of, or pertaining to, the skin.

Fate and Transport. Generic term used to describe the movement and ultimate destiny of a contaminant in a medium.

Footprint. The shape or size of a landfill-site within the horizontal plane. (i.e., the horizontal perimeter, or boundary, of the area used for burying municipal solid waste.

Geological. Those elements associated with soil or substrate type, condition, orientation, structure, etc.

Greenhouse Effect. The theory that a trend of increased global warming is occurring due to the production of greenhouse gases from natural and man-made sources.

Greenhouse Gas. Methane, carbon dioxide, and other gases capable of absorbing long wave radiation.

Hazardous Waste. As defined by the Resource Conservation and Recovery Act: A waste, or combination of wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (1) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible illness or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed (Office, 1991).

Hydrogeologic. Subsurface conditions associated with the relationships between water, soil, and substrate types, orientations, or structures.

Intermediate Fraction. That fraction of reclaimed municipal solid waste, ranging from 1/2" to 3", characterized by the presence of significant quantities of recyclables.

Landfill Reclamation (Landfill Mining). The process of removing the contents from a landfill, or landfill cell, such that the material removed is recycled, reused, reconsolidated, and/or re-buried.

Leachate. moisture, liquid, leaks, or seepage emanating from a landfill or landfill cell.

Life Cycle Cost Analysis (LCCA). Technique for analyzing the lifetime total costs, revenues, and other benefits of a project or program such that all lifetime cost and benefits are converted to present day dollars in order to provide an equal basis for comparison.

Microorganisms. a microscopic plant or animal.

Minimum attractive rate of return (MARR). The minimum interest rate or rate of return required to make an investment in a project, program, or other venture, desireable.

Municipal Solid Waste. Refuse generated by individuals, households, business, etc., including paper, plastic, metal, construction debris, soil, and other organic matter but specifically excluding hazardous waste.

National Priorities List. A document established by the Environmental Protection Agency, as a result of actions taken under the Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA), which identifies polluted locations within the United States having Federal priority in regards to the performance of clean-up or remedial action.

Net Present Value (NPV). Present value of lifetime benefits less present value of lifetime costs.

NIMBY. "Not-in-my-Backyard". A term describing public opposition to siting a facility in an area if that facility has the potential, or seems to have the potential, to adversely affect human health or the environment.

Non-aqueous Phase Liquid (NAPL). A liquid which is not readily miscible with water and having a density less than 1.0.

Organics. That which consists only of material from plant, animal, or bacterial origin.

Overs (Oversized). That fraction of reclaimed municipal solid, greater than 3" and characterized by the presence of significant quantities of recyclables.

Pathogen. Microorganisms/biological agents with the potential to adversely affect human health.

Personal Protective Equipment (PPE). Clothing/equipment designed to reduce the likelihood of exposure to pathogens, chemical agents, or other potentially harmful substances.

Recycling. The process of treating, or changing, a material so that the material may be re-used or utilized in a manner other than originally employed (Random, 1967:1201).

Reconsolidating. Process in which material is ground or otherwise reduced such that the volume to be re-buried has a smaller footprint.

Rejects. That portion of municipal solid waste that is obviously larger than 3" (e.g., white goods, rubber tires, rocks, boulders).

Synergistic. Reaction between one or more substances such that the effect on the body is greater than the effect caused by any one of the chemicals present.

Trommel. A drum, consisting of a metal frame and screen, mounted on a motorized platform such that the drum rotates for the purpose of separating material according to size.

Unders (Undersize). That fraction of reclaimed municipal solid waste less than 1/2" and characterized by the presence of significant quantities of soil and other organic matter.

Vector. Vermin, insects, and other pests commonly present in and around municipal solid waste disposal sites.

Thesis Overview

In general, later chapters of this thesis will elaborate on the issues which are introduced in this section. Specifically, Chapter II includes: a history of solid waste disposal practices as they have occurred over the last fifty years, a discussion of the need for improved methods of managing MSW, and a dialouge of the procedures, processes, and equipment required to support a reclamation project. Chapter III presents the methodology for establishing the implementation requirements of landfill reclamation as well as the systems which are used for conducting economic analysis of the benefits and costs associated with reclaiming a "typical" landfill. Chapter IV is a discussion of those aspects of reclamation which must be accomplished prior to, and during, mining operations. A decision model which aids in determining if reclamation processes are financially viable for implementation is also included. Finally, Chapter V summarizes the overall thesis document and provides final conclusions and recommendations.

II. Literature Review

Introduction.

This chapter will trace the history of landfill technology from the mid 1960s to the present and will characterize the factors which have led to the need for improved methods of managing DoD landfills. In addition, this chapter will discuss the reclamation process and related factors that affect the application of landfill mining.

History/Background.

Over the last 100 years America has been a nation of increasing population and a source of ever-growing quantities of trash and garbage. In the past, disposal of this waste was not considered a significant problem and was generally managed by the use of open dumping techniques. An open dump is a low-technology method for disposing of MSW and is described as an area where refuse is placed as a matter of convenience. Other than physical distance of these facilities from populated areas, no methods were used to control vermin, odors, or microorganisms. This method of solid waste management was commonly practiced until the 1960s when Americans finally tired of the aroma, insects, rodents, potential disease problems and other inadequacies associated with open dumps and replaced the dumps with sanitary landfills (Sayers, 1991:448).

The primary feature that distinguishes a sanitary landfill from an open dump is the existence of a "natural, or man-made, depression into which solid wastes are dumped, compressed, and covered with layers of dirt" (Sayers, 1991:448). At the point where the depression is filled to capacity, a clay cap designed to inhibit moisture from entering the system is placed over the cell to entomb the waste (Figure 2-1). This method of managing municipal solid waste provides significant control over odors, pests and airborne diseases and has made the greatest impact on controlling common solid waste disposal problems.

Although sanitary landfilling is a substantial improvement over the earlier practice of open dumping, the "vintage" sanitary landfill is not a completely adequate means of dealing with some of the problems associated with municipal solid waste disposal processes. A significant problem is control of liquid (i.e., leachate) that collects within landfill cells. Clay caps and liners, used in traditional sanitary landfills, cannot prevent all moisture from entering a landfill cell and leaving as a leachate with the potential to bear contaminants. In response to this situation state-of-the-art disposal facilities were developed.

State-of-the-art sanitary disposal facilities are equipped with leachate collection and control systems (Figure 2-2). Such systems are designed to collect leachate for on-site or off-site disposal, treatment, analysis,

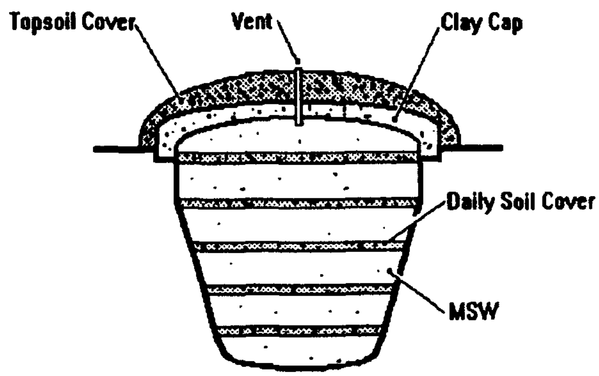


Figure 2-1. Vintage Sanitary Landfill

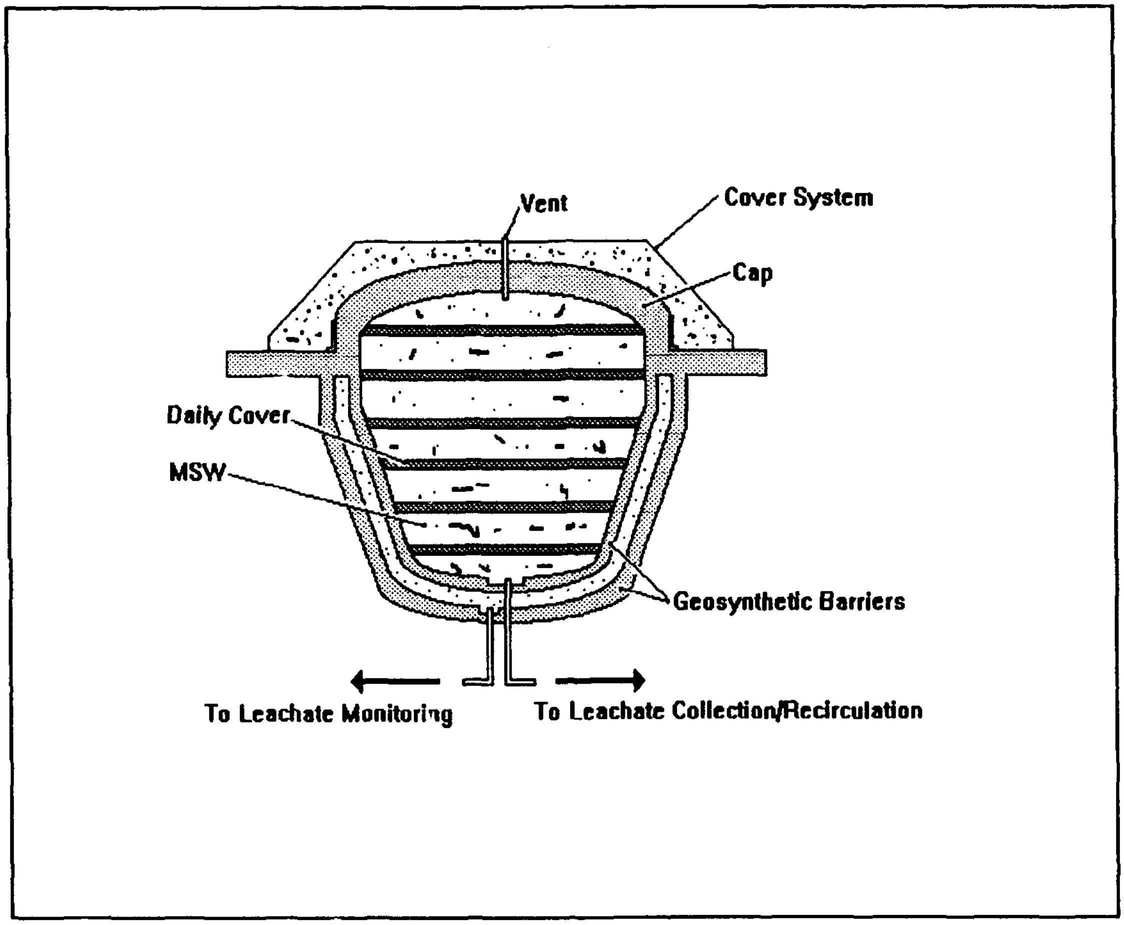


Figure 2-2. State-of-the-Art Sanitary Landfill Cell
(Wentz, 1989: 319)

and/or recirculation back to the landfill cell for the purposes of enhancing biodegradation of organic material (Wentz, 1989: 319). The state-of-the-art facility is the latest improvement to the traditional sanitary landfill because it provides a layer of protection between potential contaminants held within landfill leachate and the outside environment.

The Need for New Developments.

Other deficiencies in the methods for disposing of MSW exist because of technological limitations, growing populations, and lack of control over the type and quantity of waste being landfilled (Aldrich, 1993; Lee, 1991:32).

Clay/synthetic caps and liners, used to prevent moisture from entering and migrating through a landfill cell, are difficult to install, hard to maintain, and failure prone within twenty years of installation (Aldrich, 1993). Furthermore, capping a landfill can cause further difficulties as decomposition of organic material occurs within the anaerobic environment of the capped cell and gaseous substances are generated. Methane for example, an explosive gas, is produced within the enclosed area in quantities proportional to the decomposition rate of organic matter (Suflita, 1992: 1488).

Modern landfills require large tracts of land to remain in operation and it is not uncommon for a landfill that serves a population of 10,000 people to cover at least an acre of area and be at least ten feet deep. To further characterize the situation, approximately 145 million tons of garbage are generated each year in the United States alone (Sayers, 1991:448). These quantities are increasing at a constant rate. The quantity of MSW generated in the United States increases by two to four percent each year (Sayers, 1991: 443, 448).

Landfill Contaminants. Additional reasons for performing landfill mining are linked to the presence of chemical contamination found within landfill cells. Existing legislation requires that municipal solid waste be limited to non-hazardous material (New York, 1992: 3-53 - 3-62). Nevertheless, landfills collect a wide variety of hazardous chemical compounds and substances that are generated from household usage. Many of these compounds have known effects on human health but frequently, the actual effects of landfill chemicals on the body are unknown due to synergistic and antagonistic reactions between the compounds of concern (Burton, 1993).

Landfill leachate is normally analyzed for a wide variety of substances and physical parameters. The leachate usually has low pH, and significant hardness, biochemical oxygen demand (BOD), and chemical oxygen demand (COD). Elevated concentrations of dissolved solids, insoluble minerals, insoluble mineral compounds, (e.g., Calcium, Manganese, Sodium, Potassium, Iron, Ferrous Iron, Zinc, Nickel, Chlorides, Sulfates, Nitrates, and Phosphates) and organics are common.

Numerous other soluble metals are also found in elevated concentrations and are of critical concern as they can enter tissue readily in their soluble state. The conditions within a landfill are typically anoxic and, in these environments, sulfides readily bind with dissolved metals. Metal-sulfides are relatively stable and are unlikely to pose a health-risk given that conditions remain deoxygenated. However, if the metal-sulfide molecules are able to access aerobic environments the metals readily disassociate from the extremely stable sulfide molecules, become soluble, and are free for uptake (Burton, 1993).

Landfills also contain large amounts of organic matter undergoing the process of biodegradation. As such, decay of the material induces generation of various gases including hydrogen sulfide, carbon dioxide, hydrogen, nitrogen, nitrogen as ammonia, and in anaerobic conditions, methane (Metry, 1976: 10). Specific effects from exposure to these compounds is dependent on the gas itself. Carbon dioxide, for example, is a simple asphyxiant (Sittig, 1979:97-98).

Another hazard inherent to municipal solid waste disposal facilities is the presence of pathogens. Pathogens exist as a result of burying sanitary sewage and medical waste in the landfill with growth rates of the microorganisms a function of nutrient levels in the cell. Typical pathogenetic and non-pathogenetic analysis of landfill refuse includes tests for extracellular enzymes, aerobic bacteria, methanogens, sulfate-reducing bacteria, enteroviruses, and protozoa. Some of these organisms can cause a wide variety of diseases, rotoviral infection, hepatitis-A, and in rare cases, polio (Suflita, 1992: 1488).

Contaminant Fate and Transport. Whether chemical contaminants are immediate hazards depends upon the physical characteristics and stability of the contaminant itself. For example, the specific gravities of offending substances have a major impact upon behavior in a water column. While the ultimate fate of a contaminant is dependent on sorption and desorption, Contaminants with specific gravity greater than 1.0 will generally sink to the bottom of a water column (Figure 2-3). Exposure is relatively unlikely but clean-up, using traditional pump and treat technologies, becomes difficult. Conversely, contaminants with a specific gravity less than 1.0 will float to the surface of a water column (Figure 2-4). In this scenario, exposure is much more likely but cleanup is also easier (Goltz, 1992).

The fate of refuse contaminants depends upon a wide variety of complicated transport mechanisms within air and

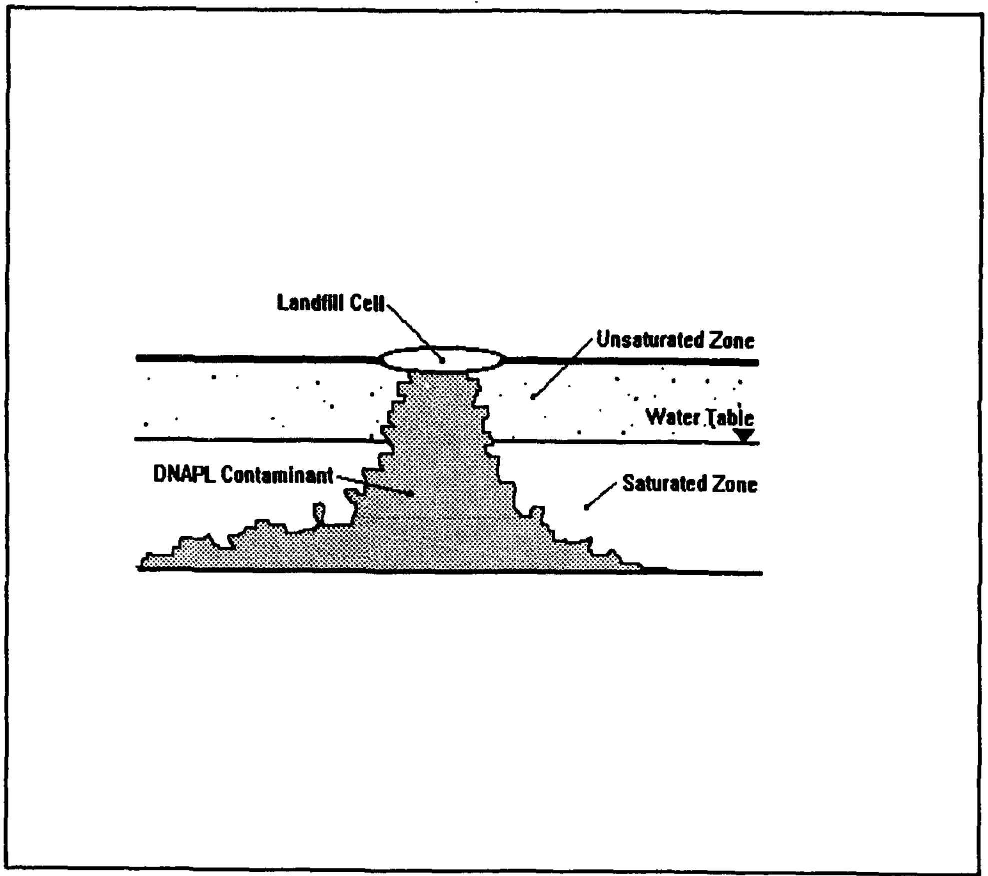


Figure 2-3. DNAPL Contaminant in Groundwater Assuming no Groundwater Flow (Goltz, 1992)

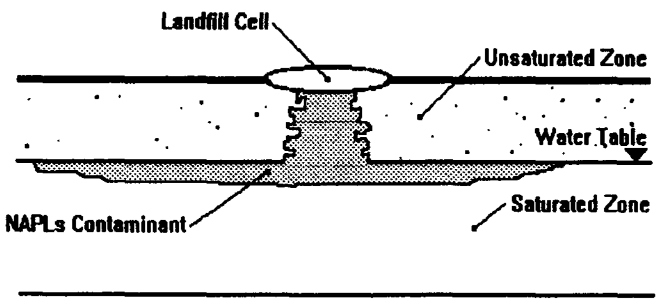


Figure 2-4. NAPL Contaminant in Groundwater (Goltz, 1992)

groundwater systems. Figure 2-5 illustrates these conditions and transport of moisture via various systems is depicted with arrows. The figure indicates that soil type and hydrogeologic characteristics are relevant factors that determine the dispersal of refuse contaminants (Wentz, 1989: 313-316).

Exposure Routes. Contaminants found in landfills are not a risk unless pathways exist for the contaminant to enter or effect the body (Ottoboni, 1991: 19-28). As such, a discussion of the routes of entry is necessary as the reclamation process entails that the risk of exposure to contaminants must be borne by the reclamation worker.

Paths of exposure from landfill contaminants commonly follow one of three routes: inhalation, dermal, and ingestion. One of the most common means by which landfill workers, individuals reclaiming landfills, and people in the surrounding community can be exposed to landfill contaminants is by inhalation. Methane, carbon dioxide and other landfill gases can come into contact with humans through the inhalation pathway. The critical issue in this case is that gaseous contaminants enter the body readily because the lungs are poor barriers to chemicals carried by atmospheric medium (Ottoboni, 1991: 46).

Most exposure, however, occurs by dermal contact with landfill leachate. Dermal exposure is characterized by penetration of the dermal and subcutaneous layers, entrance

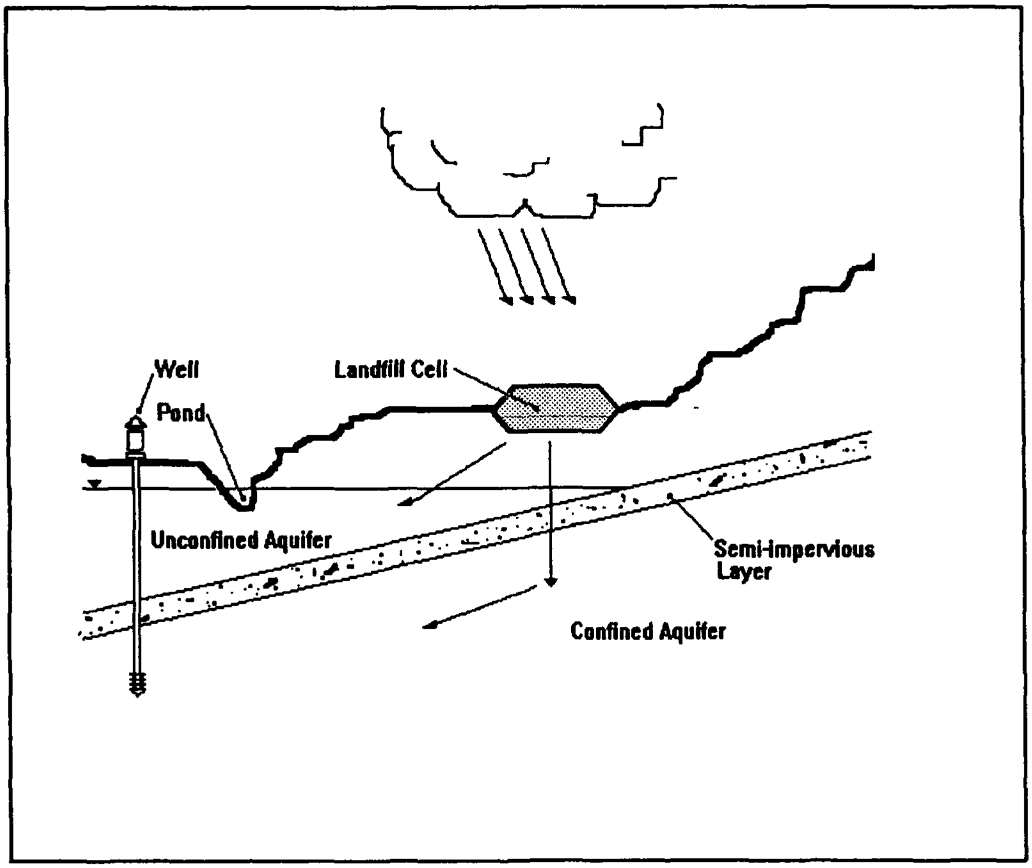


Figure 2-5. Contamination of Surface and Groundwater Sources by Leachate (Metry, 1976: 812)

to the bloodstream, and transport throughout the body (Ottoboni, 1991: 46). Exposure by this route of entry is of concern for children and sanitary landfill workers who are playing and working in potential run-off areas.

Exposure to landfill contaminants through ingestion occurs primarily through the intake of contaminated ground or surface water or food products. Once the contaminant has entered the gastro-intestinal system it can be excreted, absorbed directly through the stomach and intestines, or metabolized by the liver (Ottoboni, 1991:47).

NIMBY. A final factor which requires the development of new landfill management techniques is the "Not-in-my-Backyard" (NIMBY) syndrome. Simply stated, NIMBY is the term which describes public opposition for locating a facility in an area if that facility has the potential to adversely affect human health or the environment. The NIMBY syndrome is a source of numerous delays in the construction of waste treatment, storage, and disposal facilities and has become a factor which has a significant impact on the ultimate construction costs of these facilities (Project, 1991: 40). Fortunately, landfill reclamation can delay, for many years, the problems associated with the NIMBY syndrome as reclamation processes extend existing landfill lifetimes.

The Reclamation Processes

The objectives for conducting landfill reclamation vary from site to site but, in general, the goals for mining include one or more of the following: reclamation of the undersize fraction for on-site, or off-site, use as an economical backfill material, reclamation of material with high British thermal unit (Btu) values for the purposes of converting waste to energy, and reclamation for the purpose of decreasing the area of the landfill's footprint thus reducing ultimate closure and liability costs associated with the presence of the landfill and extending economic life.

Landfill reclamation is not a high technology process and was proven to be a successful method of solid waste management in the Spring of 1988 when it was first put into large scale use by Robert Fahey, Solid Waste Director of Collier County, Florida (Kelly, 1990:44; Lee, 1991:32). The essential philosophy behind landfill reclamation is that it is an "after-the-fact" method of recycling in which the expected life of a landfill is extended by using a specific management techniques for controlling the existing waste within the landfill as well as any future waste to be disposed. Thus, reclamation is a technique designed to keep a landfill operational as long as possible and/or keeping the landfill environmentally safe after it is closed (Kelly, 1990:44).

As stated previously, landfill reclamation is not a high-technology process and as such, is relatively inexpensive to perform. The Collier County reclamation project, for example, cost less than ten dollars per ton of waste mined (Lee, 1991:32). The mining process itself involves the use of equipment, typically used in the "earth-moving" industry, and entails exhuming and consolidating portions of a landfill as a part of a continuous strategy for managing the landfill site (Kelly, 1990:44; Read, 1993). The basic process consists of excavating individual landfill cells and separating the garbage into four basic categories. These categories are the unders (undersize) material, the overs (oversize) materials fraction, the intermediate fraction, and reject materials (Lee, 1991:32; New York, 1992: 2-13 - 2-18).

The undersize materials category consists of dirt and decomposed organics from food wastes, lawn clippings, and other material which is easily broken down by the action of microorganisms or which can pass through a 1/2 inch finger or trommel screen. Generally, this fraction makes up approximately thirty percent of a landfill's volume (Lee, 1991:32). Virtually all of the material from this category can be re-used on-site as daily cover for continued landfilling operations, or, depending on local regulatory agencies, used off-site as a low-grade backfill. In some cases this fraction can be consolidated for use in methane gas generation (Kelly, 1990:44-45).

The oversize materials category and the intermediate fraction are differentiated by the size of material after separation. The oversize fraction consists of those recyclable materials greater than three inches while the intermediate fraction consists of that material ranging between one-half inch and three inches. Both categories contain a complex mixture of components that are usually found in landfills. Typical finds within the intermediate fraction include: aluminum cans, plastic, and large quantities of recyclable components that possess high capacities for generating heat (Kelly, 1990:45; Spencer, 1991:34-35). The oversize fraction usually contains similar material but it is less easy to handle as it occurs in bulk or unwieldy sizes. These components can be separated for reuse, used as an alternative fuel in industrial applications, or broken down for composting.

Reject material is that portion of excavated waste which may be re-used but which is obviously too large to pass through a 3 inch screen and generally contains a mixture of recyclable and non-recyclable material. Typical finds include discarded white goods, rubber tires, plastic, rocks, boulders, textiles, and unidentifiable material. Items from the intermediate, oversize, and reject categories generally make up between fifty and seventy percent of a landfill's volume (Lee, 1991:32).

Advantages and Disadvantages of Mining

Conducting a landfill reclamation project can have significant benefits. The primary advantage of landfill mining is that it reduces landfill closure costs, per unit of waste disposed, in cases where the fill will continue to receive waste. Currently, landfill closure costs equal to the expense of the capping/cover system that is required to be installed during, and at the end of, a landfill's life. The cost of this system is proportional to the landfill area or waste footprint and typical closure costs are approximately $100,000 per acre (Auffinger, 1990:88; Spencer, 1991:34). Landfill mining operations can effectively reduce the footprint of a landfill by 50-70 percent (Lee, 1991:32) thus extending the landfill's life and decreasing the ultimate total closure costs. Additional controls such as using baling techniques as part of the reconsolidation effort for the portion of trash to be reburied can result in additional "two to threefold volume reductions." (Lee, 1991:32)

A second advantage of landfill reclamation is that the mining process can reduce the potential for future liability (Kelly, 1990:44). During the excavation phase, landfill reclamation allows identification of the exact types of material that have been buried in the landfill. This is a major advantage because it allows the owner to determine if hazardous waste treatment or removal actions need to occur during the landfill closure process to prevent groundwater contamination (Lee, 1991:34). Additionally, potential liability is reduced as a result of shrinkage in the landfill footprint. A pilot reclamation project conducted in Edinburg, New York reduced the area of a closed landfill, from five to four acres, by mining one acre of the total site. New York State regulatory agencies determined that no treatment or closure activities needed to occur on the one acre segment that was mined (New York, 1992: S-1).

Additional benefits of landfill reclamation also include the capability of selling the recyclables and reclaimed methane gas, the ability to upgrade the landfill to a state-of-the-art facility, or the possibility of redeveloping the landfill site for an alternative purpose after reclamation is complete (Spencer, 1991:34).

Landfill mining, with all its benefits, is not without its drawbacks. The primary disadvantage with landfill mining is in the long-term payback period for the reclamation effort. Landfill mining is not cost prohibitive. However, removing, separating, and reconsolidating the garbage requires that excavating and material separating equipment be purchased or leased.

Another major disadvantage of landfill reclamation is in the hazardous nature of the mining operation. "Workers at a landfill mining operation may be exposed to asbestos, hazardous chemicals such as chlorinated solvents, and other hazards" (Lee, 1991:33). Individuals working directly in the reclamation effort must wear personal protective equipment at all times. Training of these individuals in the proper procedures for handling hazardous waste, waste disposal, and emergency spill response training is a necessity and is another cost that must be absorbed.

Additionally, subsurface pockets of methane are common and are difficult to locate. Thus, explosion hazards do exist for those individuals conducting the mining operation. A final hazard that must also be considered is that subsurface settling of material within the landfill is inevitable. Those areas in the landfill which are susceptible to settling are difficult to predict and sinkholes are a common occurrence.

Summary

Historical techniques for disposing of municipal solid waste have improved overall conditions since the era of the open dump. Sanitary landfilling, however, is not without it's problems. One effective method for responding to the problems is a technique known as landfill reclamation.

Landfill reclamation consists of excavating material from an existing landfill, sorting, separating, and reconsolidating the material, then reusing, recycling, or reburying the processed components. There are significant advantages to reclaiming a landfill. The primary advantages include a reduction in landfill closure costs and a reduction in potential liability resulting from hazardous discharges.

Landfill reclamation is not without its disadvantages. These disadvantages include the potential for individuals who are directly working the reclamation process to be exposed to hazardous contaminants, potential problems with the presence of methane gas, and a long economic payback period.

III. Net Present Value Methodology

Background

A review of the current literature associated with mining activities will be used to establish mining requirements. Published reports on various "pilot" reclamation projects conducted within the United States present the requirements to be accomplished during mining operations and is the main focus of later chapters of this research.

Life-cycle cost/net present value (LCC/NPV) analysis constitute the analytical tools used in this thesis for examining costs and benefits of landfill reclamation, and for determining economic feasibility. Analysis entails computation of costs and benefits of landfill mining during project lifetime and converting those figures to values which are comparable.

Data Collection and Analysis

Costs, incurred during landfill mining will be identified and then converted to dollar values which are comparable with respect to time and interest rates. Some of the costs included in the analysis are capital expenses (costs of purchasing reclamation equipment and facilities), the cost of maintaining that equipment, and the costs associated with maintaining sufficient quantities of labor.

The benefits associated with landfill reclamation are treated in the same manner. Cost-avoidance, revenues, and other benefits during the lifetime of landfill mining will be converted to present dollars. Specific benefits which are part of the analysis include landfill tipping fees and revenues from the sale of glass, plastic, metal, and paper that are removed from the landfill.

Cost/benefit data are obtained from several different sources. These sources include reviews of current literature, telephone interviews with individuals who manage landfill mining projects, and individuals involved in the management of municipal solid waste programs.

An evaluation of the economic feasibility of proposed projects is made by examining the expected costs and benefits over the project's operational lifetime (Ruegg, 1987: 1). In order for these benefits and costs to have meaning, they must be analyzed in dollar values at a specific point in time and additionally, the entire time that the equipment, process or procedure is in use must be analyzed. This process is known as life cycle cost analysis or total cost accounting (Aldrich, 1993: 56).

In the case of landfill reclamation, analysis must include examination of the cost of separation equipment, labor costs, and other costs such as those related to operating and maintaining the landfill. Economic benefits, such as revenue and avoided costs, must be examined as well. For landfill reclamation projects an analysis of economic benefits includes revenue generated from the sale of recyclable/reusable material (e.g., glass, plastic, and metal) as well as the value of landfill closure costs which are avoided.

Once all of the lifetime benefit and cost data is gathered, it is necessary to compare them at one point in time. To interpret the gathered data meaningfully, it is necessary that it be presented in terms of value in "present dollars" or at a specific point in time. This is the basis of net present value (NPV) analysis. Landfill reclamation project costs and benefits occur over a project's lifetime where the lifetime is set to "n" years (Figure 3-1). Costs in year "n" cannot be legitimately compared to costs in other years due to the time value of money. The time value of money depends upon the opportunity cost of money and inflation. Similarly, benefits occurring at different years cannot be compared unless the time value of money is taken into account.

Formulas for converting these figures to present day values have been developed. For converting individual future cash flows to present-day dollars the following equation is used:

$$P=F(1+i)^{-n} \qquad (1)$$

Where:

P = present value of the payment or revenue (dollars)

F = future value or the payment or revenue (dollars)

i = discount rate per year

n = number of years

and additionally, for converting annually recurring future cash flows to present-day dollars the following equation is used:

$$P=\frac{A(1+i)^{n}-1}{i(1+i)^{n}} \qquad (2)$$

Where:

A = cost or revenue value of annuity (dollars)

Figure 3-2 shows a cash flow diagram of the costs and revenues associated with a hypothetical situation. This example has future cost payments of \$5000 at year n=5 and at year n=10. In addition, there is a revenue annuity amounting to \$1000 per year for a period of 10 years starting at year n=1. It is assumed that annual cash flows begin at year n=1. This convention represents the fact that

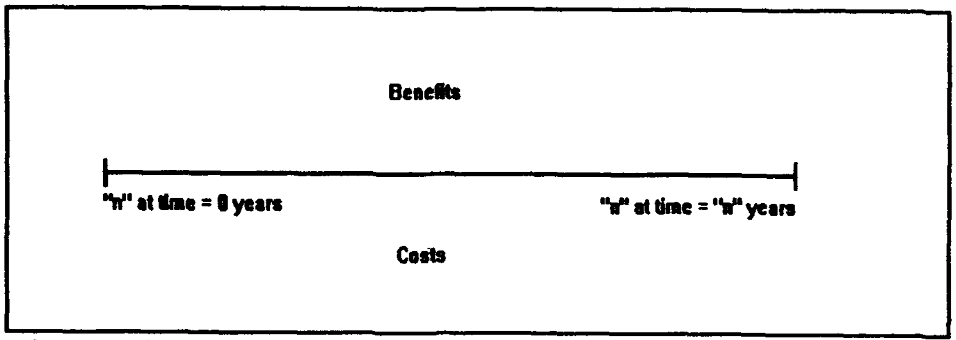


Figure 3-1. Timeline of Project Lifetime

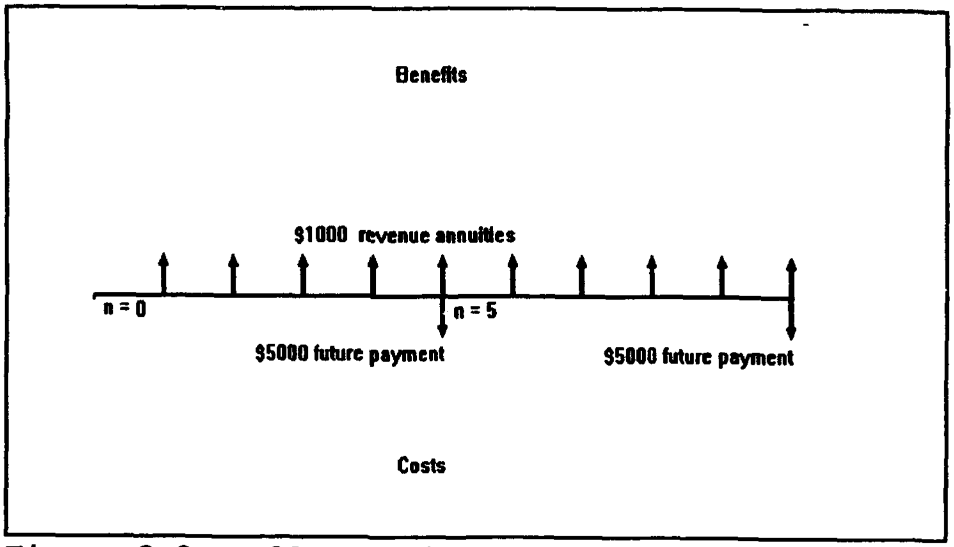


Figure 3-2. Illustration of Positive and Negative Cash Flows

investments begin payback at the end of the first year. Investments in landfill reclamation projects will follow this practice and thus, the "end-of-year-convention" will be used in the economic analysis conducted in Chapter IV. The project also has a ten year life span, and a minimum attractive rate of return (MARR) of 10% with annual compounding.

By application of Formula 2 it can be shown that the $1000 revenue annuity has a total present value of $6144.57. In similar fashion, by applying Formula 1 it can be shown that the $5,000 payment at n=5 years has a present value of $3104.61 and that the $5,000 payment at n=10 has a present value of $1927.72. Thus, the total present value of the costs is $5032.33.

Knowing the present value costs and benefits, it is possible to compare them meaningfully. In this example, the net-present value of this project equals present revenues less present costs which is $1112.34 (i.e., $6144.57 minus $5032.33).

The importance of the previous example lies in the fact that all projects, which can be expressed in terms of total cost, can be evaluated using present-value analysis. This fact holds true for landfill mining programs regardless of the amount of the cash flow, number of transactions involved, or when the cash flow occurs.

Application

LCC/NPV analysis can be applied to pollution prevention projects as a means of determining economic feasibility. To further illustrate, LCC can be applied to a hypothetical landfill reclamation project with lifetime as is represented in Figure 3-3. This figure shows annually recurring positive cash flows as a blocked area above the baseline. This represents the concept of revenues, and cost-savings, which one would expect to be uniformly recurring annuities. By the same token, uniformly recurring negative cash flows are illustrated as a blocked area below the baseline. Those positive and negative cash flows associated with the landfill reclamation project which are not uniformly recurring are singly-occurring cash flows and are represented by upward-facing and downward-facing arrows. The important concept to realize is that all benefits and costs of this hypothetical landfill reclamation project are capable of being converted to total present-day amounts and thus, the net present value (i.e., benefits less costs) can be determined.

Summary

This chapter defined the procedures for collecting, and the processes which will be used for analyzing, the data in order to accomplish the research purpose as identified in Chapter I.

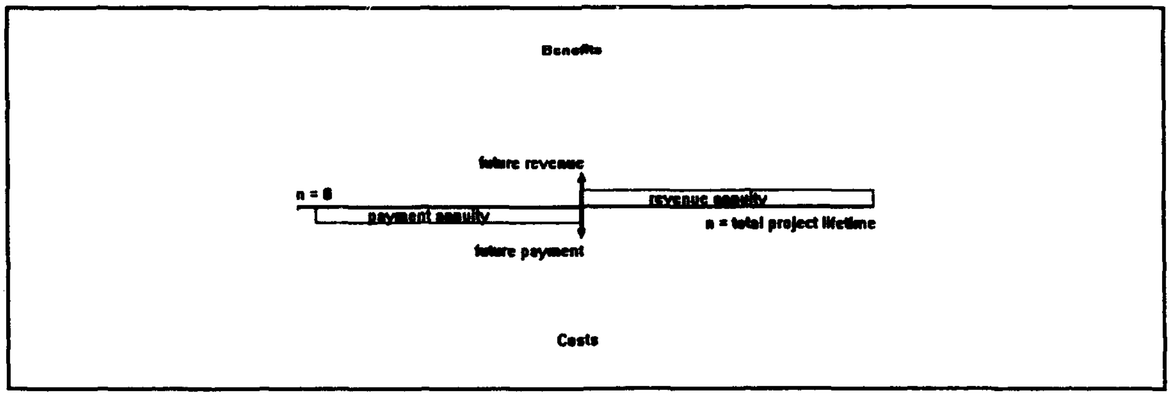


Figure 3-3. Illustration of Cash Flows for a Hypothetical Reclamation Project

The primary collection procedure used is a review of current literature but a minor amount of telephone interviews were also used. In addition, a detailed description of life cycle cost analysis and net present value analysis was made as an introduction to the methodologies to used in later chapters. Finally, examples illustrating each type of analysis were provided.

IV. Landfill Reclamation Implementation Guidelines

Introduction

This chapter discusses aspects of landfill mining projects which must be considered and accomplished prior, during, and after implementation of the reclamation program. Included in this chapter is a discussion of the primary objectives of landfill mining and the importance of establishing site-specific goals prior to progressing with the reclamation program. Additionally, this chapter stresses the importance of coordinating with local, state, federal, and other regulatory agencies early in the overall reclamation planning process. Finally, this section of the thesis discusses the major program requirements of a landfill mining program. The text concentrates on the initial research and waste characterization procedures which are important; health, safety, contingency, and reclamation planning; preparation and site-work, environmental monitoring, waste disposition, and economic feasibility of the mining process.

Goals and Objectives

Identifying the appropriate goals and objectives for conducting site-specific landfill reclamation operations is an important element of the overall mining program and is critical to the success of the reclamation effort. Additionally, when evaluating specific goals it is important to realize that landfill reclamation programs require the acceptance of concepts (e.g. recycling and re-use of disposed items) not normally associated with management of MSW and construction debris.

Specifically, the goals and objectives of landfill mining include one or more of the following (Roeder, 1993):

Recovery of recyclable materials for reuse.

Recovery of the soil/organics fraction for off-site/on-site use as a low grade backfill or compost.

Volume/liability reduction.

Waste to energy conversion.

Material recovery consists of excavating the waste, separating it into different fractions and removing the recyclable materials, such as metals, plastics, and paper, from each fraction (New York, 1992: 1-1 - 1-3). The overall viability of this particular option is dependent on the local market's ability to support re-use and re-sale of the excavated materials.

The soil recovery option consists of separating soil and organics from the rest of the waste so that the fraction may be used in one or more applications. These applications include: on-site re-use as daily cover in the active portion of a landfill, off-site re-use as a low-grade backfill, and finally, off-site use as composting material (New York, 1992: 1-1 - 1-3). The viability of this particular option is governed by decomposition levels within the landfill, contaminant levels in each fraction; local, state, or federal regulatory guidelines on acceptable contaminant levels, and capability for remediating the contaminants.

The volume/liability reduction option consists of excavating the waste, and using a combination of techniques including recycling, reconsolidation, and shipment of the waste to active portions of the landfill or to other landfills, in order to extend the existing landfill's life as long as possible. Related activities include upgrading the landfill to a state-of-the-art facility, or complete clean-closure of the site (New York, 1992: 1-1 - 1-3; Salzman, 1993).

The waste to energy option consists of separating those components having significant "Btu-value" in each fraction of waste from the remaining portion. That material which has high Btu value can be burned as an alternative fuel in a variety of applications including manufacturing, the construction industry, and electric power generation. Limitations to this option include moisture content of the waste, establishing the correct ratio of "alternative" fuel to normal fuel, and finally, accessibility to plants and facilities having adequate equipment to burn the waste efficiently and within regulatory requirements (Roeder, 1993).

Coordination

Establishing and maintaining contact with local, state, and federal environmental, safety, and health agencies is critical to the ultimate success of the landfill reclamation program and a rapport with all relevant environmental groups. In addition, the general public and organizational units of the installation can not be eliminated from coordination activities. The most effective means of coordinating project needs with base organizations and citizen action groups is to establish a forum in which issues and concerns can be addressed. For installation organizations working group to the installation environmental protection committee are extremely effective. Minimum representation should include individuals from the base environmental planning function, civil engineering, bioenvironmental engineering, logistics, safety, and the fire department. For civilian agencies, town/public meetings are appropriate for presenting information and receiving feedback. Ultimately, coordination of reclamation actions should be conducted in accordance with DoD regulations and the National Environmental Policy Act (NEPA) (Aldrich, 1993).

Reclamation Operations

Beginning Research and Waste Characterization. The first operational step in conducting landfill reclamation processes is characterization of the waste and the site to be mined. Site/waste characterization is essential in identifying the presence of hazardous contaminants or physical conditions which may preclude mining operations or which may require operations to be modified (New York,1992: 2-19 - 2-21).

Characterization of the site and the waste requires careful analysis of geologic and hydrogeologic conditions. Circumstances affecting the potential to mine a proposed site, such as an excessively high water table, must be identified. Additionally, statistically significant numbers of waste samples, based on the area of the site to be mined, must be obtained in order to identify other important characteristics of the landfill including: waste types, decomposition levels of organic matter, quantity of moisture in the unsaturated zone, and the presence of any chemical contaminant or pathogenetic microorganisms (Aldrich, 1993; New York, 1992: 2-27 - 2-39).

Results of the site/waste analysis are important in determining many operational requirements for the reclamation effort. Typically, analysis provides decision-making criteria on the overall feasibility of mining specific sites, types and configurations of equipment needed to conduct mining processes, levels of personal protective equipment to be used by on-site workers, and the applicability of other laws and regulations on the proposed site (e.g., Resource Conservation and Recovery Act [RCRA] and the Comprehensive Environmental Restoration Compensation and Liability Act [CERCLA]). Adequate completion of this phase of the mining program will provide sufficient data to conduct effective coordination with federal, state, and local regulatory agencies, installation organizations, and the general public as required under NEPA.

Health, Safety, and Contingency Planning. The next step critical to success of the overall reclamation process is preparation of plans which identify actions which will be taken, organizations which will be notified, key personnel, and procedures which will be followed for day-to-day safety requirements or in the event of a potential, or actual, health/safety problem or contingency.

The reclamation project's Health and Safety Plan (HASP) and Contingency Response Plan may be written as individual documents or may be combined into a single comprehensive document. Regardless of format, the Health and Safety component must identify emergency and day-to-day operating procedures for the project. The plan should include detailed listings of key personnel, site entry procedures and control, surface and subsurface site characterizations, personal protective equipment requirements, environmental monitoring procedures, spill response and documentation procedures, "suspect-material" holding areas, decontamination, and emergency notification/communication procedures (New York, 1992: 2-21). Additional planning considerations must be given to those risks involving potential exposure to chemical, biological, and radioactive hazards as well as the hazards of fires, explosions, excavation hazards (e.g., cave-ins/engulfment), temperature extremes and required work/rest cycles, noise, mental stress and fatigue, nuisance dusts, drums, and confined spaces (New York, 1992: 2-21 - 2-24).

Each site to be mined should have equipment dedicated to monitoring potential hazards. Specifically, combustible gas detectors, portable photoionization detectors for detecting volatile organic compounds (VOCs), radiation survey meters, and personal asbestos/organic vapor badges need to be present at each cell being excavated. Personal protective equipment must be available for all on-site workers and should, as a minimum, consist of EPA Level "C" protection including full-face air purifying respirators with high efficiency particulate/organic vapor cartridges (New York, 1992: 2-22).

The contingency response component must contain very specific elements as well. In general, the plan should identify requirements, procedures, and equipment which are to be employed in the event of a spill, leak, discharge, site-runoff, drainage, disposal, or other unplanned release (New York, 1992: 2-25).

The Contingency Plan should also specifically designate the individuals or groups responsible for providing emergency response and when emergency response should be initiated. In general, emergency response actions should be implemented (New York, 1992: 2-25 - 2-26):

When environmental monitoring equipment indicates that action levels, or permissible exposure limits (PEL), as designated in the Health and Safety Plan are exceeded.

When buried drums are encountered during digging or screening operations.

When materials which appear to be asbestos containing materials are encountered during digging or screening operations.

When compressed gas cylinders or other potential fire/explosion hazards are encountered during digging or screening operations.

When any vapors, clouds, effervescence, gas generation, out-gassing, etc. are detected during digging or screening operations.

When any unanticipated release of pollutants occurs.

When any unanticipated emergency situations occur (e.g., fire, explosion, medical emergencies).

When any other situation is identified by the project officer, contractor, or other individual, as an emergency situation or when the health and safety of the workers, environment, or surrounding population is jeopardized.

Site Work and Preparation

Reclamation Equipment. Equipment typical of that used in landfill reclamation demonstration projects consist primarily of standard earth-moving equipment (Read, 1993). A suggested heavy equipment inventory should consist of: a tracked excavator with a 2.4 cubic yard bucket for exhuming waste and loading the garbage into separation equipment; two or three rubber-wheeled loaders with 2.5 - 4 cubic yard buckets for conducting excavation, material loading, material transport, and site grading; one or two twenty-ton dump trucks for transporting rejects and screening to the

respective storage areas; and an on-call fire truck to provide fire control and suppression (Lancaster, 1992; New York,
1992: 2-8).

Additional required equipment includes machinery necessary to separate the soil and reject fraction from the bulk of the recyclable or reusable waste. Potential equipment arrangements are shown in Figures 4-1 and Figure 4-2 but many other arrangements are possible. The arrangement most suitable is dependent on site-specific conditions, moisture content of the waste, and personal preference. Additionally, soil type is an extremely important factor to consider in the selection separation equipment as some soils (e.g., clay) will stick to most equipment components and prevent efficient screening (Murphy, 1993).

At a minimum, separation equipment should consist of a shaker screen with a 3" grid and a trommel screen (Figure 4-3) with 3/4" openings. Alternatively, the shaker screen can be replaced with a vibratory finger screening device (Figure 4-4) which has the first level of fingers set at intervals of 1.5" and the second level of fingers set at 1/2" intervals. Optional equipment set-ups can consist of

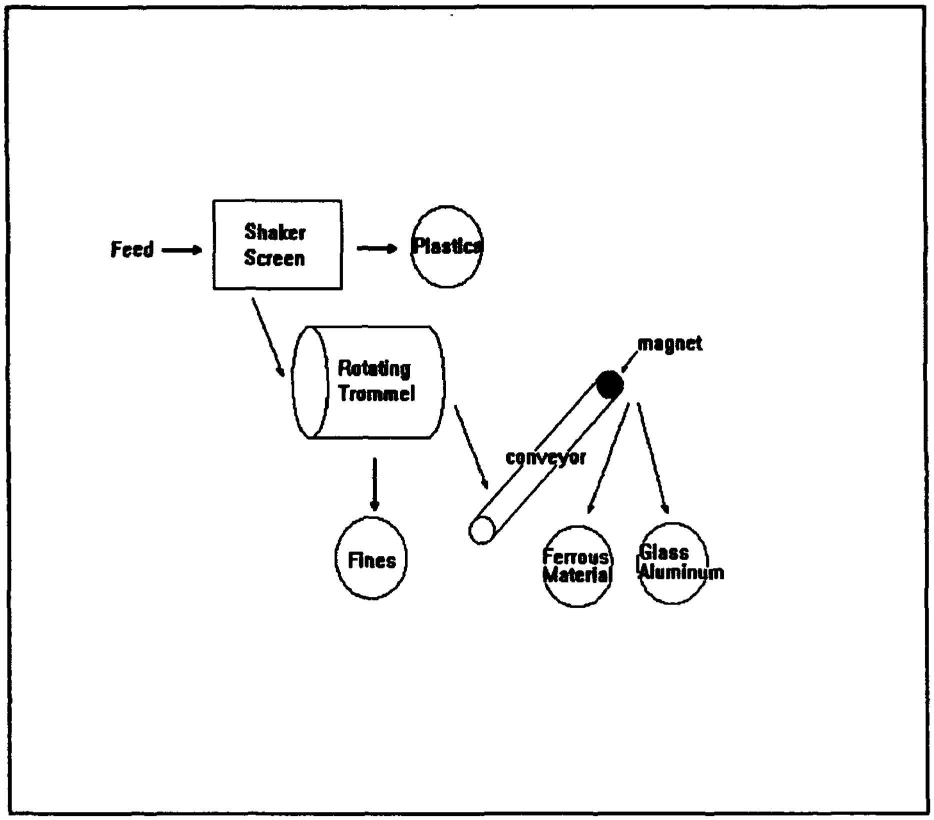


Figure 4-1. Sequenced Screening: Shaker Screen Followed by Trommel (Stessel, 1991: 10)

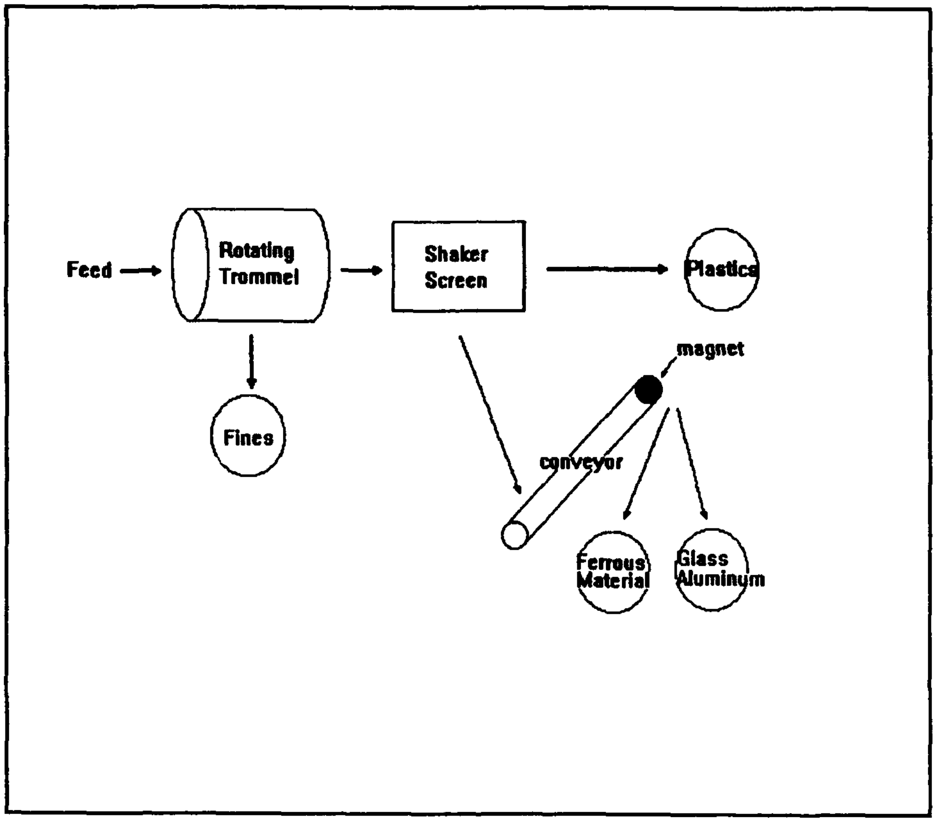


Figure 4-2. Sequenced Screening: Trommel Followed by Shaker Screen (Stessel, 1991: 11)

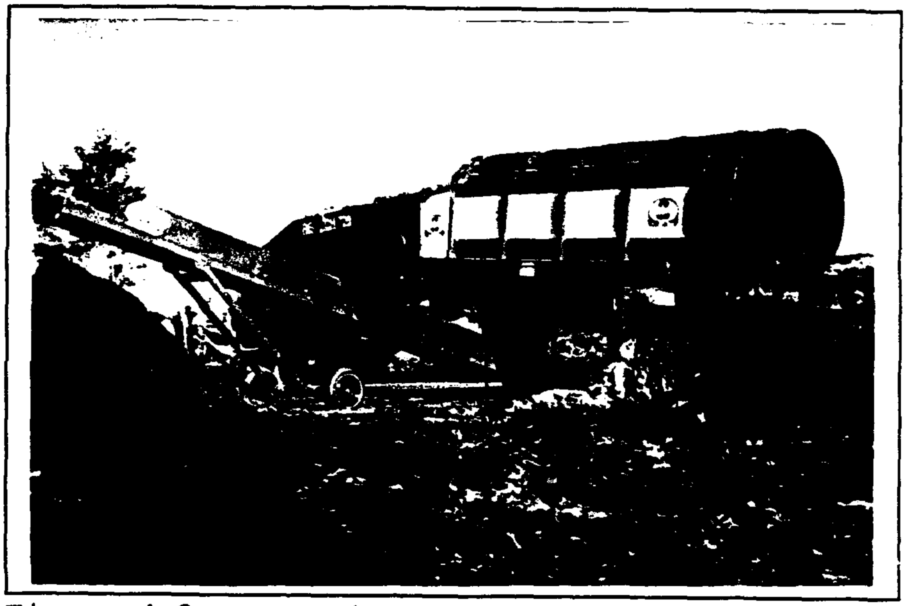


Figure 4-3. Rotating Trommel Screen Separator (Re-Tech, 1993)

Figure 4-4. Vibratory Finger Screen Separator (Waste, 1992)

grizzly-bar separators, eddy current separators, magnetic separators, and air knives (Figure 4-5).

Excavation, Site Maintenance, and Grading. The process of excavating landfill cells can be hazardous due to the inconsistent nature of the excavated material. As such, slopes on the excavated faces of a landfill should not exceed Occupational Safety and Health Administration (OSHA) standards and gradings of less than 34 degrees are desirable. Each site should be excavated horizontally, layer by layer, until the assumed bottom of the cell is reached (Figure 4-6). At that point an additional three to five feet of material should be mined to ensure as complete removal of waste as possible. At the end of each work day a soil cover should be applied to the unexcavated portion of waste to aid in vector and odor control. These processes should continue until the entire cell is completely excavated. At that time, the inert and unmarketable portion of the waste can be re-consolidated and may be placed into the cell. Adequate amounts of backfill should be used to provide desired level of cover and finish gradings which prevent ponding and allow for positive surface runoff (New York, 1992: 2-9 - 2-16).

Prior to beginning excavation pre-designated areas for placing separated materials should be identified. Excavated material which is frozen, or which has a high moisture content, should be set aside such that the waste may thaw/dry before separating (New York, 1992: 2-10). In

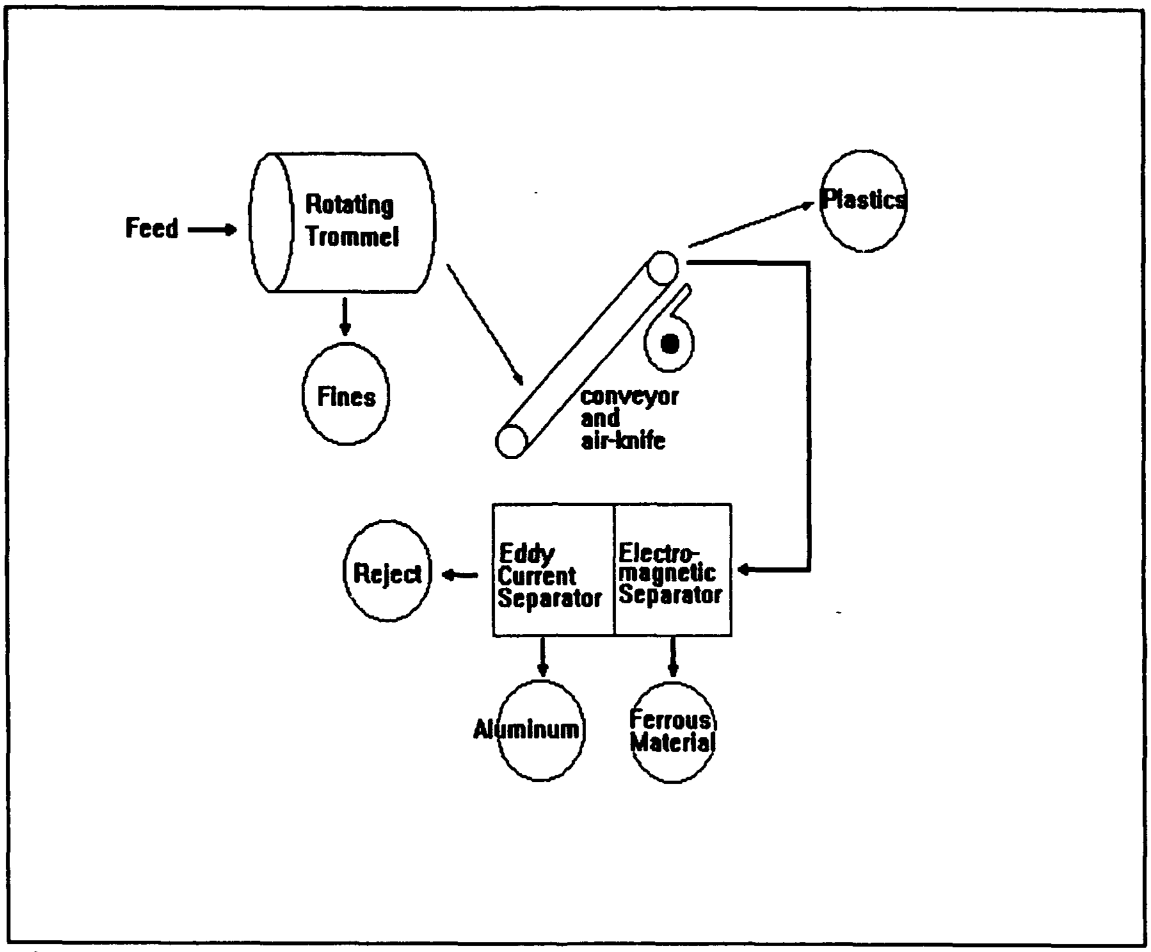


Figure 4-5. Trommel, Magnetic, and Eddy-Current Train (Stessel, 1991: 17)

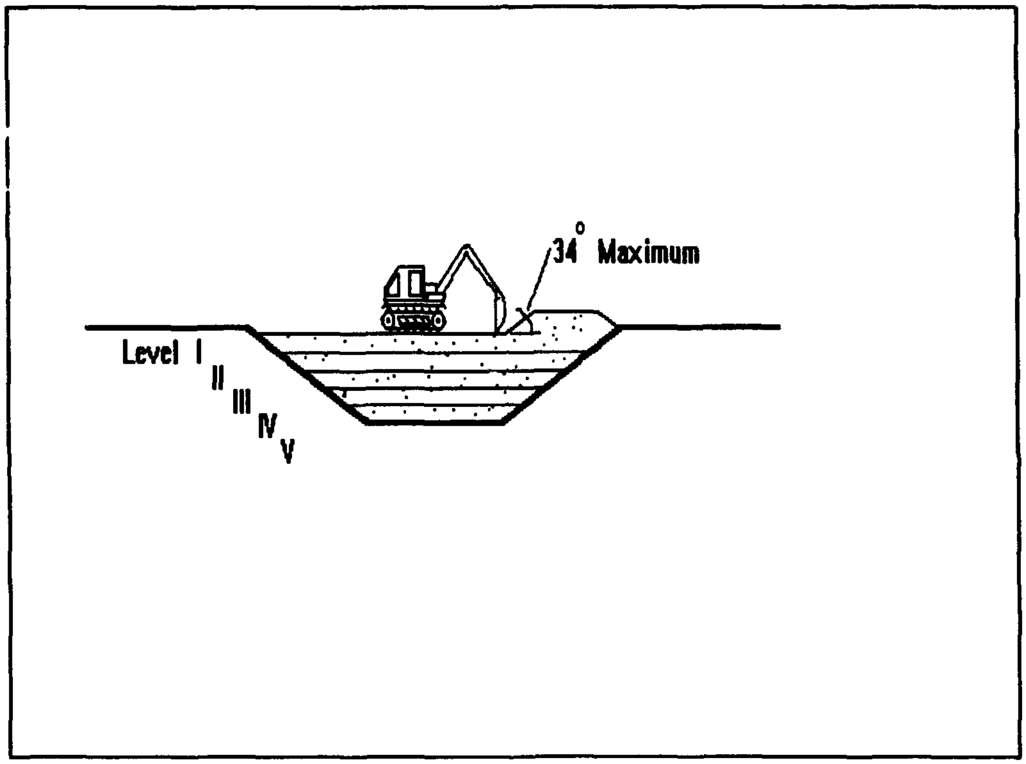


Figure 4-6. Phases of Excavation in a Landfill Mining Project

instances where the waste's moisture content is high catch basins, runoff collection systems, or surface impoundments may be necessary.

Additionally, excavation should not occur or be allowed to continue if there are indications that groundwater is, or has been, in contact with the waste. In these cases, the waste will not only be too wet to mine and separate, but more importantly, the landfill may be a source of groundwater contamination and consequently, should be evaluated under CERCLA guidelines.

Environmental Health and Monitoring. Perhaps one of the more dangerous aspects of reclaiming landfills is the potential for on-site workers to become exposed to chemical, biological, and radiological hazards. As such, monitoring these hazards, and understanding how to react to their presence is crucial in preventing worker injury and government liability. The main issues of concern for environmental monitoring of the reclamation process are determining which hazards to monitor, how often, what standards to compare against, and what to do when those standards are exceeded.

Initial and background screening for contaminants should consist of sampling for those contaminants shown in Table 4-1. Although initial sampling appears extensive, conducting analysis at this stage of the reclamation process

Table 4-1

Initial/Background Sampling and Analysis

(New York, 1992: 3-39 - 3-61)

Protocol	Parameter	Sampling Location	Justification
Compost	pH	Background Soils, Soil Screenings, and Below Waste Soils	Suitability for Use as Compost
	BOD/COD		
	Total Solids		
	Total Volatile Solids		
	Total Kjeldahl Nitrogen		
	Nitrate		
	Phosphate		
Metals	Aluminum		TCL Analysis
	Arsenic		
	Barium		
	Cadmium		
	Calcium		
	Chromium		
	Cobalt		
	Copper		
	Lead		
	Magnesium		
	Manganese		
	Mercury		
	Nickel		
	Potassium		
	Sodium		
	Vanadium		
	Zinc		

Table 4-1 (Continued)			
Protocol	**Parameter**	**Sampling Location**	**Justification**
Volatiles	Chloroform	Background and Soil Screenings	TCL
	Methylene Chloride		
	Acetone		
Semi-Volatiles			
Pesticides/PCB			
Volatiles/Semi-Volatiles		Below Waste and Soil Screenings	TCLP
Pesticides			
Metals			
Microorganisms	pseudomonas fluorescens	Background, Below Waste, and Soil Screenings	Pathogenesis Indicator
	pseudomonas putida		
	pseudomonas stutzeri		
	citrobacter freundii		
	serratia odorifera		
	bacillus sp.		
	enterobacter sp.		
	vibrio fluvialis		
	aeromonas sp.		
	proteus sp.		
	flavobacterium sp.		
	pseudomonas aeruginosa		Pathogenesis
	acinetobacter sp.		

serves as a means of identifying problem areas before full-scale reclamation begins.

After initial and background screening is complete, the number of daily sampling protocols can be reduced to searching for specific hazardous substances and indicator compounds. These protocols should include monitoring for:

Asbestos - any material, which when analyzed, is determined to be greater than 1% asbestos by weight.

Polychlorinated biphenyl (PCB) - concentrations greater than 50 parts per million.

Biochemical and Chemical Oxygen Demand (BOD/COD) - as an indicator of the need for additional biodegradation, stabilization, or treatment.

Toxicity Characteristic Leachate Procedure (TCLP) analysis - to determine the levels for specific metals, volatiles, semi-volatiles, pesticides, and herbicides which have the potential to leach from landfill soil.

Substances on the EPA's Target Compound List (TCL) - an extensive listing of common and potential contaminants again including metals, VOCs, semi-volatile organic compounds (SVOCs), pesticides, and PCBs (New York, 1992: 2-27 - 2-39).

Additionally, Table 4-2 illustrates indicator, or reduced, analysis protocols.

If the organic fraction is to be used as a composting material additional testing parameters also become important. Requirements and standards governing compost quality vary from state to state as do requirements concerning the compost's physical parameters (New York, 1992: 2-29). Consequently, evaluation of regulatory guidance is necessary.

Table 4-2

Daily/Recurring Sampling, Monitoring and Analysis

(New York, 1992: 3-39 - 3-61)

Protocol	Sampling Location	Action Level	Remarks
Combustible Gases	Work-Site Ambient Air	>10% of Lower Explosive Limit	N/A
VOCs	Work-Site Ambient Air and Personal Monitoring	Consistent Readings >5ppm or any frequent movement of the needle	Personal Organic Vapor Monitors should be analyzed for: BTEX Compounds, Acetone, Methylene Chloride, Chloroform, MEK, TCA, Isopropyl Alcohol, Hexane, Napthalene, PCE, Carbon Tetrachloride, and TCE
Radiological		>1mR/hr	N/A
Asbestos		0.2 f/cc (PEL/TWA), 1.0 f/cc (PEL/STEL)	
Fecal Streptococi	Below Waste and Soil Screenings	See Local Standards	Indicators of Suitability for Use in Compost
Fecal Coliform			
Salmonella			
Protozoa			

Waste Disposition. Alternatives for the disposition of the non-marketable fraction of waste material are varied and financial considerations are the main factor which governs ultimate disposition. Disposition methods include reconsolidation by compaction, shredding, grinding, or baling and on-site re-burial. Alternatively, the non-usable waste fraction can be exported to another landfill.

Applicable Regulations

Prior to beginning a landfill reclamation program it is essential to understand applicable laws and regulations. Although specific legislation has not been drafted for landfill mining processes, pertinent legislation does exist (Walker, 1993). This includes the National Environmental Policy Act (NEPA), the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Restoration Compensation and Liability Act (CERCLA), the Clean Air Act (CAA), and the Clean Water Act (CWA).

NEPA. NEPA is the federal legislation which requires government agencies to consider the environment in their decisions. In basic terms, the law requires that major federal actions, and alternatives to these actions, be evaluated for the potential to impact specific areas of environmental concern (e.g., air, water, wetlands, natural and cultural resources). The act also allows specific types of actions to be excluded from extensive analysis in the absence of unusual or extenuating circumstances. However, the law also requires public participation in the decision-making process. Consequently, the use of categorical exclusions may not be the best alternative when considering landfill mining. Regardless or whether or not a substantial amount of evaluation is conducted, familiarity with the requirements of NEPA must be fully understood prior to beginning landfill reclamation activities.

RCRA. Sufficient knowledge of RCRA requirements is also critical to the success of landfill mining operations. RCRA provides guidance for day to day management of hazardous wastes and details the requirements for handling, transport, treatment, storage, and disposal of hazardous waste. Assuming that encounters with hazardous waste are certain during any given landfill reclamation operation, it is apparent that an awareness of the requirements of RCRA is necessary.

Furthermore, revisions to basic RCRA requirements, which apply specifically to new or expanding landfills, have been drafted and are found in the new "Subtitle-D" section (Nichols, 1992:18). In general, the revised RCRA legislation imposes siting restrictions, regulates new landfill design, monitoring, closure/post-closure plans, and methods of daily operation (Rogoff, 1992:21).

CERCLA. CERCLA is another major law which may have to be taken into account as a result of landfill mining processes. CERCLA, also known as "Superfund", provides guidance for investigating, evaluating, and remediating hazardous waste sites. If analysis indicates that the landfill contains contaminants, which cannot be immediately removed or remediated, then it is necessary to implement CERCLA requirements and in all probability it is unlikely that the fill can be mined.

CAA. A working knowledge of CAA requirements is also essential to conducting landfill mining procedures. The main focus of the CAA is protection of air quality by the establishment of Air Quality Control Regions (AQCRs), National Ambient Air Quality Standards (NAAQS), and State Implementation Plans (SIPs) for attaining/maintaining air quality.

Specific designations for, AQCRs include:

Attainment Areas - Where ambient air quality standards are being met.

Non-attainment Areas - Where ambient air quality standards are not being met.

Unclassifiable Areas - Where classification of a particular area can not be made on the basis of existing information.

Furthermore, NAAQS are ambient air standards for "criteria" pollutants which include sulfur dioxide, particulate matter less than ten microns, carbon monoxide, ozone, oxides of nitrogen, and lead. The standards for these criteria pollutants are met through SIPs in which each state generates a plan which provides for meeting ambient air requirements for each AQCR within that state.

The CAA is a complicated law which addresses many issues in regards to air pollution issues. Understanding the basic requirements of the CAA, location-specific SIPs, and familiarity with the allowable quantities of criteria pollutants in an AQCR which supports landfill mining is an important task in the overall mining effort.

CWA. The Clean Water Act becomes important in a landfill reclamation program if it is expected that point source, or non-point source, run-off will occur as a result of reclamation operations.

In basic terms, the CWA focuses on eliminating the discharge of pollutants into national waterways through the establishment of a pollutant discharge permitting system. Permits are issued for, among other practices, dredged or fill material dumping, industrial discharge, and municipal/industrial stormwater discharges. Existing permits specifically identify the quantity and types of pollutants that may be discharged into the navigable waters of the United States. As such, under landfill reclamation processes, it is important to know authorized quantities of pollutants which may be discharged under existing permits, whether an existing permit needs to be modified, or if a new permit must be obtained.

Economic Analysis

This section provides a guide for examining the costs and benefits of landfill reclamation. The overall intent is to supply a basis by which the economic feasibility of landfill reclamation can be estimated within varying geographic areas and market conditions.

Model Assumptions. The following assumptions apply to the development and use of this model:

Time. In this model the effective time period in which economic analysis should be conducted for a landfill reclamation project is as follows:

$$[T(1+L)]-T \qquad (3)$$

Where:

T = Normal expected lifetime of the landfill without reclamation (years).

L = Expected volume reduction in the landfill due to the introduction of reclamation processes (percent).

For the analysis conducted in this thesis, the effective period of economic analysis is established by assuming that the normal lifespan of a MSW landfill is twenty years and that landfill reclamation allows waste volume reductions of seventy percent (Lee, 1991: 32). Thus the assumed time period in which landfill reclamation can be performed, and the assumed period of economic analysis is:

20 years (1 +.70) = 34 years. Consequently,

34 years - 20 years = 14 years.

Discount Rate. A minimum attractive rate of return (MARR) of ten percent is used in all present value calculations as is typical for federal government projects (Aldrich, 1993; Ruegg, 1987: 37).

Landfill Assumptions. The physical conditions of the "hypothetical" landfill used as basis for analysis are as shown in Table 4-3. Waste types, and percentages of waste by weight, as shown in Figure 2-2 have been repeated in Table 4-4 as a matter of convenience.

Table 4-3

Assumed Physical Characteristics of a Landfill

(New York, 1992:3-23, 6-28; Stessel, 1991: 22)

Characteristic Element	Characteristic Data
Landfill Area	5 Acres
Landfill Depth	25 Feet
Total Reclaimable Volume	261,667 Cubic Yards
Total Reclaimable Weight @ 2 Tons/Cubic Yard	523,334 Tons
Rate at which Waste is Received	37,381 Tons/Year
Mining Rate	37,381 Tons/Year

Benefit Identification. The following elements are benefits, or income generating, components of landfill reclamation. Additionally, although landfill mining results in a significant reduction to future liability, and a related reduction in future costs, that reduction is difficult to quantify. As such, long-term liability costs are not included in this economic analysis. The end result however, is a more conservative model in that it eliminates some of the potential benefits of landfill mining and as such, results in a lower net present value.

Table 4-4

Waste Types and Percentages by Weight

(Murphy, 1993)

Waste Type	Percentage of Landfill by Weight
Metals	6.3%
Plastic	7.0%
Paper	9.7%
Glass	5.1%
Construction Debris, Rock, and other Inorganics	50%
Organics	4.2%
Other (rubber, textiles, etc.)	17.7%

Tipping Fees. Tipping fee benefits are those funds saved as a result of allowing an existing landfill to continue operations and receive waste during reclamation rather than paying for the waste to be disposed elsewhere. Table 4-5 indicates the regional average and effective range of tipping fees to be used in the economic evaluation.

Closure Costs. In general, closure costs are those which are incurred as a result of requirements to cap and monitor municipal solid waste landfills at the time of closure. With landfill reclamation, closure costs are avoided because landfill reclamation entails removal of all hazardous components leaving only the inert fraction at the time of ultimate closure (New York, 1992: S-1). As such, those costs which are normally be incurred as part of landfill closure are avoided and can be realized as a cost savings or benefit. Specifically, the majority of the closure cost which are avoided are associated with capping, or moisture barriers, and post-closure monitoring. The range of cost savings for these line-items are shown in Table 4-6.

Marketable Recyclables. The range of potential revenues from the sale of recyclables is shown in Table 4-7. Given this data, the background data as shown in Table 4-3, and the quantity of recyclables as shown in Table 4-4, a price range for yearly sales of recyclables can be developed and is shown in Table 4-8.

Table 4-5

Regional Average and Effective Range of Tipping Fees (adjusted for inflation)

(Solid, 1987)

Region	Average Tipping Fee	Tipping Fees Saved through Reclamation
Southeast United States	$21/Ton	N/A
Northern United States	$37/Ton	
Southern United States	$31/Ton	
Central United States	$27/Ton	
New England	$50/Ton	
Western United States	$17/Ton	
Mid-Western United States	$18/Ton	
Effective Range	$17 - $50 per ton	$635,000 to $1,900,000 per year

Table 4-6

Landfill Closure and Post-Closure Costs

(New York, 1992: 6-28; Means, 1992:497-505)

Cost Element	Cost Range
Capping Fee	$500,000 to $750,000/site
Long-term Monitoring and Maintenance	$9,000 to $16,000/year

Table 4-7 Range of Potential Benefits from Sale of Recyclables (Hill, 1993; Recycling Manager, 1993:2-3)	
Waste Type	**Range of Potential Benefits**
Metals (ferrous and non-ferrous)	$39 to $62/ton
Plastic (baled)	$32 to $156/ton
Paper	$67 to $117/ton
Glass	$16 to $52/ton
Construction Debris	$4 to $47/ton
Compost/Backfill/Organics	$4 to $5/ton

Table 4-8 Price Range for Yearly Sales of Recyclables		
Waste Type	Yearly Reclaimable Quantity	Range of Income from Sale of Recyclables
Metal	2,355 Tons	$92,000 to $146,000 per year
Plastic	2,617 Tons	$84,000 to $408,000 per year
Paper	3,626 Tons	$243,000 to $424,000 per year
Glass	1,906 Tons	$31,000 to $99,000 per year
Construction Debris	18,691 Tons	$75,000 to $878,000 per year
Organics	1,570 Tons	$6,000 to $8,000 per year

Costs Identification. The following elements are costs or income reducing components of landfill reclamation.

Equipment Costs. The cost of the minimum equipment necessary for performing landfill mining are shown in Table 4-9 and include equipment operator costs.

Labor Costs. The labor costs for the minimum number of individuals necessary to perform a landfill reclamation project are shown in Table 4-10.

Table 4-9
Landfill Reclamation Equipment Costs

(Lancaster, 1993; Means, 1992: 13-15; Read, 1993)

Equipment Type	Potential Range of Costs
Tracked Excavator (1 each)	$155,000 to $261,000/year
Loader (2 each)	$253,000 to $427,000/year
Dump Trucks (3 each)	$258,000 to $435,000/year
Screening Device (1 each)	$40,000 to $114,000
Rotating Trommel (1 each)	$116,000 to $195,000

Operations and Maintenance Costs. The operations and maintenance costs for a minimum landfill mining operation are as shown in Table 4-11.

Table 4-10

Landfill Reclamation Labor Costs

(Lancaster, 1993; Means, 1992: 4-93)

Type of Labor	Potential Range of Costs
Managing Engineer (1 each, committing 5% of total available hours to reclamation operations)	$2,000 to $4,000/year
On-site Supervisor (1 each, committing 50% of total available hours to reclamation operations)	$35,000 to $58,000/year
Waste Inspector (1 each, committing 100% of total available hours to reclamation operations)	$42,000 to $72,000/year
Laborer/Maintenance (1 each, committing 25% of total available hours to reclamation operations)	$11,000 to $19,000/year

Table 4-11

Landfill Mining Operations and Maintenance Costs

(Lancaster,1993; Means,1992: 13-15; New York,1992: 6-28)

O&M Cost Element	Potential Range of Costs
Equipment/Vehicle fuel and maintenance	$33,000 to $55,000 per year
Background Testing and Analysis	$3,000 to $5,000 per site
Initial Screening	$31,000 to $52,000 per five acre site
Daily soil/waste screening	$10,000 to $17,000 per year

__Present Value Calculations__. Given benefit and cost data, four separate market conditions, based on the dollar figures from Table 4-3 through 4-11, are identifiable. These market conditions are those in which landfill reclamation can be analyzed for economic feasibility. The conditions are the high-benefit/low-cost market, the high-benefit/high-cost market, the low-benefit/low-cost market, and the low-benefit/high-cost market.

The high-benefit/low-cost market is that market in which higher dollar values for sales of recyclables, and higher dollar values of cost-savings, are realized. At the same time, costs for conducting landfill reclamation are low. Conversely, in the low-benefit/high-cost market the dollar values which are realized for sales of recyclables, and dollar values of cost-savings, are low. At the same time, costs for conducting reclamation operations are high.

Net present value analysis is conducted for each market by importing the appropriate dollar figures into cash flow diagrams representing the associated market conditions. Figure 4-7 through Figure 4-14 depict the cash flows and the resulting net present values for each of these market conditions and, in accordance with Formula 2, a factor of 7.37 is used for converting recurring payments to present dollars with i=.10 and n=14.

Further examination of the figures show that the net present value of landfill reclamation is positive in all but low-benefit/high cost markets and as such, under most

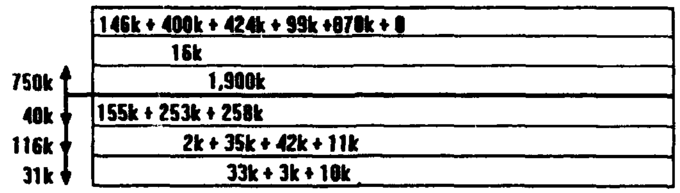
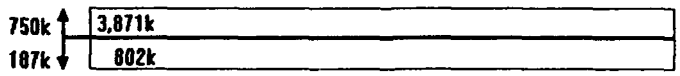


Figure 4-7. Reclamation Cash Flows in High-Benefit/Low-Cost Market



$$NPV = (750k + [3{,}871k \times 7.37]) - (187k + [802k \times 7.37])$$

$$= (750k + 28{,}529k) - (187k + 5{,}911k)$$

$$= 29{,}279k - 6{,}098k$$

$$= 23{,}181k$$

Figure 4-8. Simplified Cash Flows and Net Present Value of Reclamation in High-Benefit/Low-Cost Market

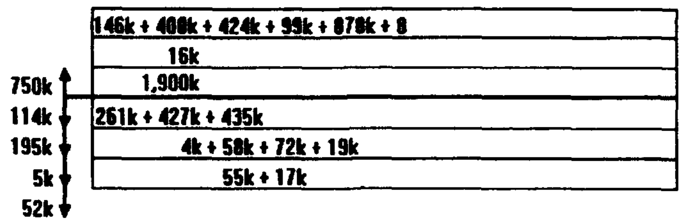
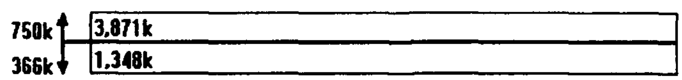


Figure 4-9. Reclamation Cash Flows in High-Benefit/High-Cost Market



NPV = (750k + [3,871k x 7.37]) - (366k + [1,348k x 7.37])

= (750k + 28,529k) - (366k + 9,935k)

= 29,279k - 10,301k

= 18,978k

Figure 4-10. Simplified Cash Flows and Net Present Value of Reclamation in High-Benefit/High-Cost Market

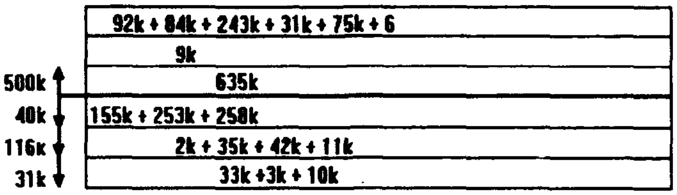
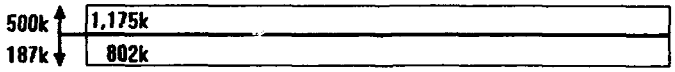


Figure 4-11. Reclamation Cash Flows in Low-Benefit/Low-Cost Market



$$
\begin{aligned}
NPV &= (500k + [1{,}175k \times 7.37]) - (187k + [802k \times 7.37]) \\
&= (500k + 8{,}660k) - (187k + 5{,}911k) \\
&= 9{,}160k - 6{,}098k \\
&= 3{,}062k
\end{aligned}
$$

Figure 4-12. Simplified Cash Flows and Net Present Value of Reclamation in Low-Benefit/Low-Cost Market

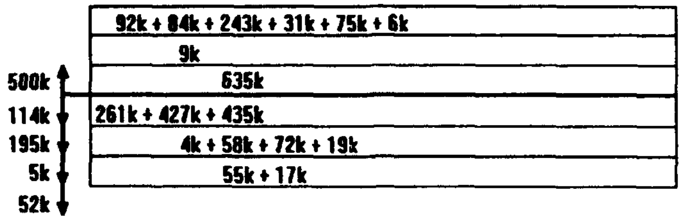


Figure 4-13. Reclamation Cash Flows in Low-Benefit/High-Cost Market

$$NPV = [500k + [1{,}175k \times 7.37]] - [366k + [1{,}348k \times 7.37]]$$

$$= [500k + 8{,}660k] - [366k + 9{,}935k]$$

$$= 9{,}160k - 10{,}301k$$

$$= -1{,}141k$$

Figure 4-14. Simplified Cash Flows and Net Present Value of Reclamation in Low-Benefit/High-Cost Market conditions, landfill reclamation is economically feasible to implement. To further illustrate how net present values of each market condition were determined, Table 4-12 and Table 4-13 depict, for high-benefit/low-cost market conditions, how the cash flow diagrams for each remaining market condition are developed.

Sensitivity Analysis. Examination of Figure 4-7 through Figure 4-14 also reveals that the single element having the highest value in each cash flow diagram, and thus having the most significant affect on the net present value, is landfill tipping fees. In Figure 4-7 through Figure 4-14 tipping fees are accounted for as benefits due to the fact that, as long as the landfill remains in operation, tipping fees to dispose of waste elsewhere need not be paid. However, assuming a scenario in which conditions no longer permit tipping fees to be avoided (i.e., "non-optimal" conditions), the net present values of reclamation change dramatically and are as shown in Figure 4-15 through Figure 4-18. As is apparent, the net present value of reclamation, where payment of tipping fees is unavoidable, is significantly negative in all but the high-benefit/low-cost market conditions. Furthermore, given the worst case scenario, a low-benefit/high cost market, a MARR of 547% is necessary to break-even.

Table 4-12

Development of Cash Flow Diagram in Figure 4-7

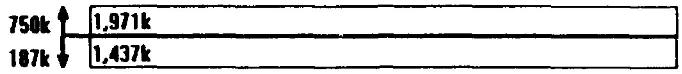
Dollar Value in Fig. 4-7	Description	Type of Cash Flow	Reference
$ 146,000	Sales of Recyclables	Positive Recurring	Table 4-8
400,000			
424,000			
99,000			
878,000			
8,000			
16,000	Monitoring and Maintenance		Table 4-6
1,900,000	Tipping Fees		Table 4-5
750,000	Capping Fees	Positive Discrete	Table 4-6
155,000	Equipment Costs	Negative Recurring	Table 4-9
253,000			
258,000			
2,000	Labor Costs		Table 4-10
35,000			
42,000			
11,000			
33,000	O&M Costs		Table 4-11
3,000			
10,000			
40,000	Equipment Costs	Negative Discrete	Table 4-9
116,000			
31,000	O&M Costs		Table 4-11

Table 4-13

Development of Cash Flow Diagram in Figure 4-8

Dollar Value in Figure 4-8	Type of Cash Flow	Reference
$3,871,000	Positive Recurring	Sum of positive recurring cash flows in Figure 4-7
750,000	Positive Discrete	Sum of positive discrete cash flows in Figure 4-7
882,000	Negative Recurring	Sum of negative recurring cash flows in Figure 4-7
187,000	Negative Discrete	Sum of negative discrete cash flows in Figure 4-7

percent is necessary to break-even. Thus, it is apparent that the avoidance of tipping fees, and mining of currently operational landfills, is critical to the economic success of landfill reclamation.



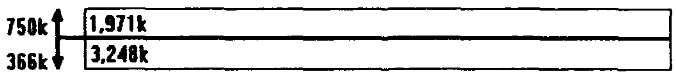
$$NPV = [750k + (1{,}971k \times 7.37)] - [187k + (1{,}437k \times 7.37)]$$

$$= (750k + 14{,}526k) - (187k + 10{,}591k)$$

$$= 15{,}276k - 10{,}778k$$

$$= 4{,}498k$$

Figure 4-15. Simplified Cash Flows and Net Present Value of Reclamation in Non-Optimal High-Benefit/Low-Cost Market



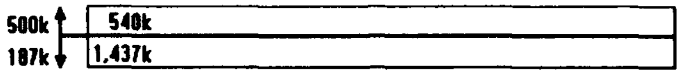
$$NPV = [750k + (1{,}971k \times 7.37)] - [366k + (3{,}248k \times 7.37)]$$

$$= (750k + 14{,}526k) - (366k + 23{,}938k)$$

$$= 15{,}276k - 24{,}304k$$

$$= -9{,}028k$$

Figure 4-16. Simplified Cash Flows and Net Present Value of Reclamation in Non-Optimal High-Benefit/High-Cost Market



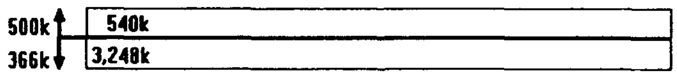
$$NPV = [500k + (540k \times 7.37)] - [187k + (1{,}437k \times 7.37)]$$

$$= (500k + 3{,}980k) - (187k + 10{,}591k)$$

$$= 4{,}480k - 10{,}778k$$

$$= -6{,}298k$$

Figure 4-17. Simplified Cash Flows and Net Present Value of Reclamation in Non-Optimal Low-Benefit/Low-Cost Market



$$NPV = [500k + (540k \times 7.37)] - [366k + (3{,}248k \times 7.37)]$$

$$= (500k + 3{,}980k) - (366k + 23{,}938k)$$

$$= 4{,}480k - 24{,}304k$$

$$= -19{,}824$$

Figure 4-18. Simplified Cash Flows and Net Present Value of Reclamation in Non-Optimal Low-Benefit/High-Cost Market

V. Summary, Conclusions, and Recommendations

Summary

As presented in earlier chapters of this thesis the DoD, and the United States in general, are in a precarious situation. The quantity of waste being generated by the American people is constantly increasing and at the same time, the amount of space currently used for landfilling solid waste is continuously being depleted. This condition, combined with the reality that the American people desire alternatives to incineration and construction of new landfills, requires that new, and perhaps controversial, techniques be used for the future management of municipal solid waste.

One technique that could have considerable advantages is the process of landfill reclamation or landfill mining. Typical benefits include the potential for recycling the once discarded resources which are now found within landfill cells.

Additionally, reclamation allows the expected lifetime of municipal solid waste and construction debris landfills to be extended. In today's economy landfill space is at a premium and as such, that space which remains in existence must be used efficiently and economically. Fortunately, reclamation allows landfills to continue operating beyond their normally expected life-spans and as such, results in efficient use of available space at lower cost.

The most significant advantage to conducting landfill reclamation is that the process reduces, or eliminates, potential for future economic liability. As the mining process entails excavation of waste-filled cells, hazardous waste, and other dangerous substances, can be identified and removed before becoming sources of risk to human health or the environment. Consequently, the opportunity for pollution incidents to occur is reduced or eliminated as is the related financial liability to owners and users of the landfill.

Another potential benefit, related to the previous example, includes the capability of eliminating closure and post-closure costs. Again, landfill mining not only entails removal of that material which can be recycled and re-sold but also includes removal of potentially hazardous chemicals and substances. The end-result of these removal actions is that an "empty" landfill (i.e., one which contains only inert material) is risk free. As such, the need for capping and post-closure monitoring is eliminated and consequently, the related expenses of performing these tasks are avoided.

The landfill mining process itself is not complex and consists, primarily, of those actions typically involved with earth-moving operations. The basic process consists of excavating the contents of a landfill cell and by means of various pieces of specialized equipment, separating the waste into different fractions. These fractions are further sorted based on the type of material left in each major fraction after initial separation.

The most difficult part of implementing a reclamation project is not in the actual operational elements of the process but is in the development of the planning and management procedures. Of these, perhaps the most critical is coordinating mining activities with local, state, and federal regulatory agencies. It is safe to assume that a non-supportive relationship with regulatory authorities are detrimental to conducting reclamation procedures and, in all probability, prevent the possibility of reclaiming landfills if bad relationships exist. Thus, rapport and good working relationships are essential.

Additionally, planning and pre-planning the reclamation effort is critical to overall success. One portion of planning entails drafting specific documents to guide operational and day-to-day aspects of the mining effort. The Health and Safety Plan, for example, should provide detailed guidance on the procedures, processes, and equipment which will be used to maintain worker and personnel safety. The plan should address what actions will be taken in the event of worker exposure to hazards, site entry/security procedures, worker evacuation procedures, and other occupational-related emergencies.

The Contingency Response Plan is another pre-requisite to beginning the landfill mining process. This plan is probably the most critical in that it details the actions which will be taken in the event of any condition which threatens public health or the environment. The plan describes which actions will be taken in a hazardous materials discharge or release incident, the responsibilities of emergency response teams, notification requirements, and how overall health and the environment will be protected.

A final plan required to be accomplished before beginning reclamation processes is the Environmental Monitoring Plan. This plan, which is just as critical as the others, is necessary to identify how background sampling, initial screening, and daily analysis for hazardous constituents will be conducted. Typically the plan will address sample collection techniques, chain-of-custody procedures, analysis and reporting requirements as well as how sampling will be conducted to achieve and maintain statistical significance.

Economically speaking, landfill reclamation has considerable promise. Mining processes are feasible in a wide variety of economic market conditions including the following "polar" market conditions: high-benefit/high-cost, high-benefit/low-cost, low-benefit/low-cost. For each of these market conditions, the net present value of the benefits can exceed the net present value of the costs.

Conclusions and Recommendations

Alternatives to traditional methods of disposal must be implemented. Landfill space does exist it is being depleted rapidly and is becoming more expensive to use. Reclamation serves as an excellent addition to established municipal and construction waste disposal practices and in many ways, should be much more palatable to the general public than construction of new disposal facilities. Although waste-mining technology simply delays the inevitable fact that the space available for burying solid waste will eventually be depleted, landfill mining will remain a viable alternative to traditional practices. DoD installations should investigate the potential for implementing reclamation process for on-site MSW and construction debris disposal areas. Where possible, DoD installations should encourage contracted waste disposal operators, who receive government waste, to initiate reclamation activities at their facilities.

Economic feasibility of landfill mining is directly related to the assumption that a landfill undergoing the reclamation process can and will remain in operation, and continue to receive, and process, new waste. Given this qualification, landfill reclamation is viable in a wide variety of economic markets. Whenever possible, operational landfills should be chosen as "priority" candidates for reclamation operations. In cases where realizing tipping fees as costs are unavoidable, present value calculations indicate significantly negative net present values. Therefore, justifying landfill reclamation processes to installation decision makers may be difficult and as such, thorough discussions of intangible and unknown benefits (e.g., liability reduction, public support and confidence) should be conducted.

One final advantage landfill mining is related to the liability issue. Although liability is difficult to quantify, it is potentially the most significant benefit of reclamation. As stated previously, reclamation provides the potential to allow hazardous substances, wastes, and chemicals to be identified and removed before they become threats to human health or the environment.

In conclusion, landfill reclamation is a viable alternative to traditional solid waste management practices. Given satisfactory pre-mining conditions it is economically feasible in a wide variety of market conditions and additionally, promotes conservation of natural resources. Costs associated with closure and post-closure of traditional facilities are eliminated as is the potential for future liability to the federal government. As such, reclamation should be considered for implementation for landfills owned, used, or operated by the DoD.

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13. ABSTRACT (Maximum 200 words)

This thesis serves as a guide for implementing landfill reclamation techniques on municipal solid waste or construction debris landfills owned, operated, or used by the DoD. The research describes historical and current methods for disposing of solid waste including open dumping, sanitary landfilling, and the development of "state-of-the-art" sanitary landfill cell technology. The thesis also identifies the factors which have led to the need for new methods of managing municipal solid waste. The vast majority of the study is devoted to identifying actions which should be taken before, during, and after implementation of a landfill reclamation project. These actions include the development of health, safety, and contingency planning documents, the establishment of systems for characterizing and monitoring site conditions, and the identification of other procedures and processes necessary for performing successful operations. Finally, this study contains a model for analyzing under which conditions reclamation is economically feasible. The model examines economic feasibility in four separate conditions and shows that reclamation is economically feasible in a wide variety of markets. However, the model also shows that feasibility is directly associated with a continuance of normal landfilling operations.

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